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Volume V

Tracking and Data System Support for Surveyor Mission VII

N. A. Renzetti

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
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Preface

The work described in this report was performed by the tracking and data acquisition organizations of the Jet Propulsion Laboratory, Air Force Eastern Test Range, Manned Space Flight Network, and the NASA Communications Network of Goddard Space Flight Center.

This volume is the fifth in a series of five to record the technical activities of the Tracking and Data System in support of the flights of *Surveyors I–VII*. Volume I covers *Surveyor* Missions I and II. Volume II covers the support of *Surveyors III* and *IV*; and Volumes III, IV, and V record the tracking and data acquisition activities for *Surveyors V, VI,* and *VII*, respectively.

Acknowledgment

The author expresses gratitude to the planning engineers and operational staff members of the participating groups and agencies who made valued contributions of skill, knowledge, and dedication to the Tracking and Data System support that was provided the *Surveyor* Project.

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Abstract

This report covers the Tracking and Data System (TDS) activities for *Surveyor VII*, from the time the requirements on the system were established by the project objectives and the spacecraft design, through the preparation of the network-support plans, the implementation of the necessary facility configurations, the performance of the requisite tests to establish operational readiness, the support of the actual flights to the end of each mission—with a comprehensive account of the tracking operations, and an evaluation of that support. To better define the requirements on the TDS, the *Surveyor* Mission objectives are reviewed and descriptions of the *Atlas/Centaur* launch vehicle and of the spacecraft are included, as is the synopsis of the seventh *Surveyor* flight. Associated equipment and activities of the three elements of the Deep Space Network, (i.e., the Deep Space Instrumentation Facility, the Ground Communications Facility, and the Space Flight Operations Facility) in meeting the metric, telemetry, command, and tracking demands of the missions are documented. Tracking and telemetry summaries of the initial phase of the flight cover operations of the Goddard Space Flight Center, the Air Force Eastern Test Range, the Spacecraft Monitoring Facility at Cape Kennedy, and the Ascension Island Spacecraft Command and Guidance Station. Technical and statistical data concerning launch, trajectory, operating modes, tracking time, received-signal levels, command lockups, and data transmission and reduction are presented.

Tracking and Data System Support for *Surveyor*

Mission VII

I. Introduction

This document provides a history of the Tracking and Data System (TDS) activities in support of *Surveyor* Missions A–G (identified after launch as *Surveyors I–VII*). Included in this document are the tracking and data acquisition (TDA) requirements; mission preparations of all participating agencies; a comprehensive account of the tracking operations; and a TDS performance evaluation summary. A brief description of the TDS for the *Surveyor* missions—as well as launch vehicles, spacecraft, and flight objectives—is also provided to convey an understanding of TDS activities.

The *Surveyor* Project was managed by the Jet Propulsion Laboratory for the NASA Office of Space Science and Applications. The project was supported by four major administrative and functional elements or systems:

(1) Launch Vehicle System.

(2) Spacecraft System.

(3) Tracking and Data System.

(4) Mission Operations System.

In addition to overall project management, JPL was assigned the management responsibility for the Spacecraft, Tracking and Data, and Mission Operations Systems. The Lewis Research Center was assigned the responsibility for the *Atlas/Centaur* Launch Vehicle System.

A. Summary of Significant Technical Activities Relating to Tracking and Data Acquisition Support for *Surveyor*

The *Surveyor* Project was the first space project to have its telecommunications function at S-band. When the project was initiated in 1960, those people responsible for the management of the frequency spectrum strongly recommended that there be no further L-band projects, such as *Ranger* and *Mariner II*, but that future projects such as *Surveyor* should be planned at S-band. In 1960, it was expected that the first flight of *Surveyor* would be in the fall of 1963. It subsequently became apparent that this objective could not be met (in fact, *Surveyor I* was not launched until May 1966). The first actual project to use S-band in flight was the *Mariner* Mars 1964 Mission.

The *Surveyor* Project provided the first spacecraft design that was wholly dependent upon commands from the ground stations of the Deep Space Network (DSN) for its inflight activities. It was significant that there was not much redundancy in the network for commanding at any single station. Thus, time-critical command activities were backed up by having other stations on line—rather than having, for example, such redundancy as two transmitter chains at each station. An example of the latter case is the Manned Space Flight Network (MSFN) configuration for the *Apollo* Project.

The *Surveyor* Project was the first deep space project to make extensive use of high bit rates, requiring the extensive use of high-speed data lines from the Deep Space Stations (DSSs) to the Space Flight Operations Facility (SFOF) in Pasadena, as a primary mode for the conduct of space flight operations. Considerable equipment was configured and experience obtained at bit rates up to 4400 bits/s from the Goldstone complex and up to 1100 bits/s from the overseas stations through the ground communications facility into data processing systems of the SFOF. Prior to this project, teletype circuits served as the primary means for transferring data and conducting spacecraft flight operations.

Additionally, the *Surveyor* Project was the first deep space project to make extensive use of real-time high-speed (greater than 50 bits/s) data processing with the IBM 7044–7094 computer system in the SFOF. This required, at times, two such computer strings to be fully operational for extended periods, especially during transit to the lunar surface. The support for this requirement was successfully provided, requiring however, many man-hours of hardware and software development and complex operational activities.

The *Surveyor* Project philosophy of highly centralized control of space flight operations required high reliability of communications circuits from the Deep Space Stations to the SFOF. This reliability was achieved by providing considerable redundancy, culminating in the first operational use of a communication satellite over the Atlantic Ocean for deep space data acquisition.

Development of the *Surveyor* spacecraft required the use of equipment and facilities for compatibility testing requiring an extensive series of tests at Goldstone with a telecommunication model of the *Surveyor* spacecraft. The availability of these facilities and the model spacecraft provided a basis for extensive training of network personnel in acquisition problems and the many varied communications procedures required to cope with the design of the *Surveyor* spacecraft. Furthermore, this project was one of the first to use the Cape Kennedy Deep Space Station (DSS 71). This station is located in the vicinity of the launch pad and checkout facilities, and was used in the final compatibility tests between the flight spacecraft and the Deep Space Network.

The *Surveyor* Project was the first to make use of the Ascension Island Deep Space Station (DSS 72), the Spacecraft Command and Guidance Station for near-earth telemetry coverage, tracking for early orbit determination, and at times, filling gaps between the coverage of other Deep Space Stations.

The *Surveyor* Project provided mission-dependent equipment at each of the Deep Space Stations for the functions of sending commands and processing telemetry and video data from the spacecraft. This equipment underwent considerable compatibility testing where it interfaced with mission-independent or network equipment. It was a source of many interface problems, not only in the hardware area, but in documentation, operations, and procedures. Stimulated, in part, by the need for extensive interface agreements because of the wide use of mission-dependent equipment throughout the TDS, procedures were developed to encompass interface structure and documentation, configuration control and documentation, as well as operational documentation for both mission-independent and mission-dependent equipment. The above procedures were developed to such a high degree that they have been implemented to support all subsequent flight projects. Furthermore, the project provided the personnel to maintain and operate this equipment, pending the training and transfer of responsibility to the on-site personnel. The project also provided on-site personnel for spacecraft control and data analysis in the event of a catastrophic failure in communications between the Deep Space Stations and the SFOF in Pasadena.

The DSN provided the support of its highest performance station, the Mars Deep Space Station (DSS 14) at Goldstone, to provide better signal-to-noise magnetic tape recordings of the strain-gage telemetry measurements during the *Surveyor I* touchdown. The *Surveyor* spacecraft, radiating from the moon, provided an excellent far field source for the Mars Station's 210-ft antenna pattern measurement (Fig. 1). The higher performance capability of this station was also used to return 4400-bit/s telemetry data during the trajectory correction maneuver of the spacecraft.

The *Surveyor* Project provided the first opportunity to demonstrate the capability to perform automatic data quality comparison in real-time on telemetry data received simultaneously from two Deep Space Stations. This function was accomplished by the telemetry processing system using two PDP-7 computers in the SFOF.

The project provided the first occasion for data commutations of pulse-code-modulated (PCM) telemetry data using a combination of hardware and software. This function was also accomplished in the telemetry processing system within the SFOF, and permitted automatic recognition of spacecraft data mode change from the telemetry system.

Fig. 1. Goldstone, Calif., Mars station (DSS 14) 210-ft antenna

The *Surveyor* Project was the first flight project wherein video information was received, retransmitted, processed, and displayed in real-time for operational decision making.

The *Surveyor* Project was the first project to share (with the *Mariner* Venus 67 Mission) the multiple project usage of a computer string.

The *Surveyor* Project was the first flight project that required the real-time transmission of spacecraft telemetry data from the near-earth phase network—i.e., from the Air Force Eastern Test Range (AFETR) ship and land stations and, in the later missions, from the MSFN station at Carnarvon to DSS 42. It brought together close working relationships between the three supporting networks: the AFETR, the MSFN, and the DSN. This integration was achieved to a degree never before attained for the support of a space flight program.

The *Surveyor* Project was the first to use: (1) real-time simulation of maneuvers with coordinated tracking and telemetry data, (2) video simulation, and (3) high-speed telemetry simulation data to overseas stations in real-time, by using the outgoing side of the high-speed data line to each of the Deep Space Stations.

B. Tracking and Data System

The TDS provided the tracking and communications link between the space vehicle and committed earth-based stations. For the *Surveyor* missions, the TDS used the facilities of: (1) the AFETR for tracking and telemetry of the spacecraft and vehicle during the launch and near-earth phases; (2) the MSFN and the NASA Communications System (NASCOM), both of which are operated by the Goddard Space Flight Center (GSFC); and (3) the DSN, for precision tracking commands, telemetry, communications, data transmission, processing, and computing.

1. Air Force Eastern Test Range. This range extends from the eastern United States mainland, through the south Atlantic Ocean area, eastward into the Indian Ocean. It includes all stations, sites, ocean areas, and air space necessary to conduct missile and space vehicle test and development. Administrative and management activities are largely concentrated at Patrick Air Force Base; actual missile launches and flight tests are conducted at Cape Kennedy Air Force Station (CKAFS) and over the downrange areas. Major instrumentation systems are used to support projects, programs, and organizations that use the AFETR launch facilities.

As a part of the Tracking and Data System, the AFETR performed tracking and data acquisition functions for the *Surveyor* missions during the countdown and launch phases of each flight. To meet its tracking and telemetry commitments for those missions, AFETR used land-based instrumentation sites, range instrumentation ships (RISs), and range telemetry aircraft.

2. Manned Space Flight Network. This network is under the direction of the GSFC. located at Greenbelt, Md. It is part of a worldwide network designed for supporting the near-earth manned space flight effort. The MSFN had certain responsibilities of tracking and data acquisition, communications, and computer support placed upon it by the *Surveyor* Project.

From the MSFN facilities, launch, first tracking, and launch *mark* event activities were monitored. By use of the switching communications and monitoring arrangements, voice operations and control were linked to all MSFN tracking stations committed to support the *Surveyor* missions.

All MSFN stations are tied together through common timing, geodetic, control systems, and communications coordination by GSFC. The worldwide NASA communications network designated NASCOM provided teletype, voice, and data links in support of *Surveyor*.

3. Deep Space Network. The DSN, established by the NASA Office of Tracking and Data Acquisition, is under the system management and technical direction of JPL. It is responsible for two-way communications with unmanned spacecraft from approximately 10,000 mi from earth to interplanetary distances. Present facilities permit simultaneous control of a newly launched spacecraft and one already in flight. In preparation for the increased number of U.S. space activities, capability is being developed for simultaneous control of either two newly launched spacecraft plus two in flight, or four spacecraft in flight. Advanced communications techniques are being implemented to obtain data from, and track spacecraft to, planets as distant as Jupiter.

The DSN is distinct from other NASA networks, such as the Space Tracking and Data Acquisition Network, which tracks earth-orbiting scientific and communications satellites, and the MSFN, which tracks the manned spacecraft of the *Gemini* and *Apollo* Projects.

The network supports (or has supported) the following NASA space exploration projects: (1) the *Ranger,* *Mariner*, and *Surveyor* Projects of JPL, (2) the *Lunar Orbiter* Project of the Langley Research Center, (3) the *Pioneer* Project of the Ames Research Center, (4) the *Apollo* Project of the Manned Spacecraft Center (as backup to certain stations of the MSFN), and (5) the NASA *Voyager* Project. The main elements of the network are the Deep Space Instrumentation Facility (DSIF), with communications and tracking stations located around the world; the ground communications facility (GCF), which provides communications between all elements of the DSN; and the SFOF, which is the command and control center for DSN-supported projects.

The Deep Space Stations are situated so that three prime stations will always be approximately 120 deg apart in longitude so that a spacecraft in or near the ecliptic plane is always within the field of view of at least one of the selected ground antennas. The Deep Space Stations and their respective locations are shown in Table 1.

The critical flight maneuvers and nearly all of the picture-taking operations during each mission were commanded and recorded by DSS 11 during its view periods. A few picture sequences were obtained by DSSs 42 and 51, which served as prime stations for tracking and monitoring of engineering telemetry for *Surveyor I*. Deep Space Stations 12, 14 (with its 210-ft antenna), 61, and 72 were configured for monitoring and backup operations during the *Surveyor I* Mission.

Acquisition of a spacecraft signal may involve six different functions:

(1) Pointing the antenna at the spacecraft.

(2) Tuning and locking receivers to the spacecraft transmitted frequency.

(3) Tuning and locking the ground transmitter to the spacecraft receiver frequency.

(4) Establishing range lock (where applicable).

(5) Synchronizing the telemetry system.

(6) In some cases, providing for immediate command transmission to the spacecraft.

Selected Deep Space Stations are equipped with acquisition aid antennas mounted on the 85-ft antennas to assist in the acquisition process. The acquisition aids

Table 1. Deep Space Station designations and locations

Location	DSS No.	Geodetic latitude, deg	Geodetic longitude, deg	Height above mean sea level, m	Geocentric latitude, deg	Geocentric longitude, deg	Geocentric radius, km
Pioneer Deep Space Station Goldstone, Calif.	11	35.38950 N	243.15175 E	1037.5	35.20805 N	243.15080 E	6372.0341
Echo Deep Space Station Goldstone, Calif.	12	35.29986 N	243.19539 E	989.5	35.11861 N	243.19445 E	6372.0176
Venus Deep Space Station Goldstone, Calif.	13	35.24772 N	243.20599 E	1213.5	35.06662 N	243.20507 E	6372.2599
Mars Deep Space Station Goldstone, Calif.	14	35.42528 N	243.12222 E	1160	35.24376 N	243.12127 E	6372.1341
Woomera Deep Space Station Island Lagoon, Australia	41	31.38314 S	136.88614 E	144.8	31.21236 S	136.88614 E	6372.5317
Tidbinbilla Deep Space Station Canberra, Australia	42	35.40111 S	148.98027 E	654	35.21962 S	148.98027 E	6371.6686
Johannesburg Deep Space Station Johannesburg, S. Africa	51	25.88921 S	27.68570 E	1398.1	25.73876 S	27.68558 E	6375.5415
Robledo Deep Space Station Madrid, Spain	61	40.429 N	355.751 E	800	40.238 N	355.751 E	6370.0868
Spacecraft Monitoring Station Cape Kennedy, Fla.	71	28.48713 N	279.42315 E	4.0	28.32648 N	279.42315 E	6373.2913
Spacecraft Command and Guidance Station Ascension Island, S. Atlantic	72	7.95474 S	345.67242 E	526.7	7.89991 S	345.67362 E	6378.2386

have beamwidths of approximately 16 deg and are accurately boresighted with the 85-ft antennas. They have angle-error outputs that are connected to a separate angle-channel receiver. By observing the angle errors generated simultaneously by both wide- and narrow-beamwidth antennas, a smooth change from tracking with the acquisition aid to tracking with the 85-ft antenna can be effected. Tracking, telemetry, and control of the spacecraft are thus properly attained.

C. Surveyor Project

The *Surveyor* Project comprised seven flights—identified prior to launch as Missions A–G and after launch as *Surveyors I–VII*—that were conducted under the auspices of NASA. Essentially, the objectives were to accomplish successful soft landings on the moon (as demonstrated by the operation of the spacecraft subsequent to landing), to provide data on the performance of the spacecraft in the transit environment and basic knowledge of the moon's structure and environment in support of the *Apollo* Project.

1. Mission flight objectives. These objectives were ordered in three priorities: primary, secondary, and tertiary. Prior to *Surveyor I* launch, a launch-hold criterion established that all objectives must be capable of being met before launch would be permitted.

a. Primary flight objectives. Achievement of the primary objectives was required for the mission to be considered successful. When developmental or operational conditions existed that jeopardized or prevented achievement of the primary objectives, the launch was delayed or rescheduled. Further, nonstandard procedures, if required, were executed during flight operations in such a manner as to accomplish the primary objectives at the expense of the lesser objectives.

The primary flight objectives were to:

(1) Demonstrate the capability of the *Surveyor* spacecraft to perform successful midcourse and terminal maneuvers and soft landing on the moon.

(2) Demonstrate the capability of the *Atlas/Centaur* vehicle to successfully inject the *Surveyor* spacecraft on a lunar-intercept trajectory.

(3) Demonstrate the capability of the *Surveyor* communications system and the DSN to maintain communications with the spacecraft during its flight and after the soft landing.

b. Secondary flight objectives. Achievement of the secondary objectives was highly desirable; however, failure to achieve these objectives, although serious, was not regarded as mission failure. The scheduled launch would probably be delayed, or rescheduled if conditions existed that seriously jeopardized or prevented achievement of the secondary objectives—but a decision would be made at that time based on the circumstances.

The secondary flight objectives were to:

(1) Obtain inflight engineering data on all spacecraft subsystems used in the cruise phase of the flight.

(2) Obtain inflight engineering data on all spacecraft subsystems used during the midcourse maneuver, terminal-descent maneuver, and main retromaneuver phase.

(3) Obtain inflight engineering data on the performance of the closed-loop terminal-descent guidance and control system, consisting of the doppler velocity sensor and altitude marking radar, on-board analog computer, autopilot, and vernier engines.

(4) Obtain engineering data on the performance of spacecraft subsystems used on the lunar surface.

c. Tertiary flight objectives. Achievement of the tertiary objectives was considered a bonus. If developmental, launch, transit, or lunar (e.g., landing site lighting) readiness conditions that affected the accomplishment of the tertiary objectives were not satisfactory, the scheduled launch would proceed as planned without major delays.

The tertiary flight objectives were to:

(1) Obtain postlanding TV pictures of a spacecraft footpad and the immediately surrounding lunar surface material.

(2) Obtain postlanding TV pictures of the lunar topography.

(3) Obtain data on the radar reflectivity of the lunar surface.

(4) Obtain data on the bearing strength of the lunar surface.

(5) Obtain spacecraft temperature data on the lunar surface for use in the analysis of lunar surface temperatures.

d. Additional mission objectives. These objectives were to:

(1) Develop the requisite technology and accomplish a series of soft landings on selected areas of the lunar surface.

(2) Transport and soft-land selected scientific instruments and perform experiments on the lunar surface for local area investigation.

(3) Obtain engineering data regarding performance of the spacecraft system that would aid in future space exploration.

(4) Telemeter the scientific and engineering data back to earth for retrieval, reduction, and dissemination.

2. Flight description. The *Surveyor* spacecraft were launched from AFETR launch complex 36 at Cape Kennedy, Fla. *Atlas/Centaur* launch vehicles were used to boost the spacecraft to the required lunar-transfer trajectory. The ascent mode used for *Surveyor* was either by direct-ascent or parking-orbit trajectory. Direct-ascent trajectories are characterized by nearly continuous thrusting from liftoff to injection; parking-orbit trajectories are characterized by a coast period of up to 20-min duration followed by a second burn injecting the spacecraft into its lunar-transfer trajectory. A single-burn, direct-ascent trajectory was used for *Surveyors I, II,* and *IV. Surveyors III, V, VI,* and *VII* used a parking-orbit trajectory.

In the absence of a parking-orbit coast capability, injection is constrained to occur at an earth-centered, central angle of about 28 deg from the launch site. Consequently, the true anomaly at injection must be varied with launch time to satisfy the time-variant geometry requirements of the transfer trajectory. To vary the true anomaly at injection, the injection flight-path angle must be varied accordingly. Since payload capability is dependent upon injection flight-path angle, the true anomaly at injection cannot exceed the limits dictated by the payload requirement for a given mission. In general, the lower true anomaly limit will delay the opening of the launch window until the required geometry is obtained. This prevents use of the lower launch azimuths on certain days in the launch period.

A lunar trajectory is usually dependent upon four impact parameters: (1) speed, (2) selenographic latitude, (3) selenographic longitude, and (4) time of lunar impact. Other sets of four parameters can be used, but this set was the most useful for the *Surveyor* missions. Corresponding to the four impact parameters are four launch parameters by which the trajectory can also be specified. They are: (1) launch time, (2) launch azimuth, (3) injection flight-path angle, and (4) energy. In the trajectory design, the impact parameters are used as search variables; the launch parameters are the control variables.

An analytic direct-ascent *Atlas/Centaur* boost model was developed that computed the injection conditions of the translunar trajectory associated with a given set of launch parameters. When the injection conditions are obtained, the trajectory may then be computed.

The nominal *Surveyor* trajectories were selected on the basis of the launch and impact parameters previously described and the constraints imposed on them. The functional relationships involved in the selection of these parameters in trajectory design are presented in Fig. 2. This diagram shows the dependence of the parameters upon the geometry of the lunar orbit and the mission design constraints. The dependence of the output of the design (i.e., the launch windows and periods, impact speeds, and landing locations) upon these parameters is shown.

When all of the *Surveyor* launch constraints are fully satisfied, the *Atlas/Centaur* launch vehicle is ready for firing. Two seconds after liftoff, the *Atlas* autopilot rolls the vehicle to the required heading, and the pitch program is initiated after 15 s of vertical flight. When the axial-thrust acceleration reaches 5.8 *g* (approximately 142 s after liftoff), the *Atlas* booster engines are shut down and jettisoned. At *Atlas* propellant depletion, approximately 238 s after liftoff, the sustainer engine is shut down and the *Centaur* main engine start sequence begins. After the *Atlas* is jettisoned, the *Centaur* main engine ignites. Injection into the required lunar-transfer trajectory occurs at *Centaur* main engine cutoff, approximately 680 s after liftoff. Shortly after injection, a *Centaur* programmer command deploys the spacecraft landing gear and omnidirectional antennas, and switches the spacecraft transmitter to high power. The spacecraft is then separated from the *Centaur.* At this time, *Centaur* executes a retromaneuver to remove itself from the vicinity of the spacecraft and to prevent interference with the spacecraft Canopus sensor later in the flight.

The lunar-transfer trajectory can be approximated by a highly eccentric ellipse having one focus at the earth's center. Typical values for the eccentricity and semimajor axis are 0.98 and 384,000 km, respectively. The

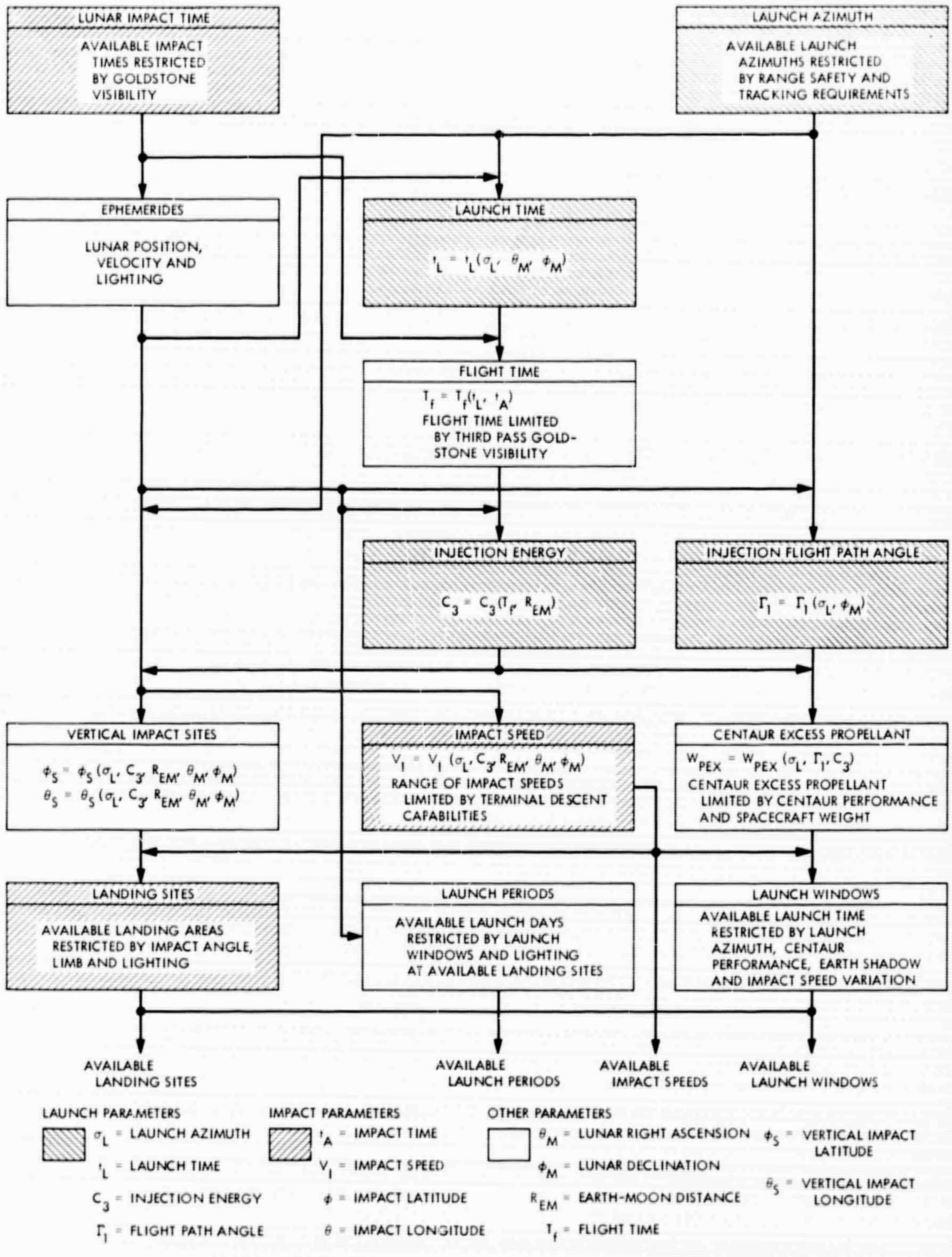


Fig. 2. Functional relationships between launch parameters, impact parameters, mission design constraints, and *Surveyor* trajectory design

perigee altitude is 90 nmi. Lunar encounter occurs at approximately one half the distance from perigee to apogee.

After separation from the *Centaur*, the spacecraft cold gas jets null the rotational rates imparted during separation. Solar panel erection and sun acquisition are accomplished automatically. This is the standard condition of the spacecraft at the initial DSS 51 acquisition. In a nonstandard condition, DSS 51 will send the commands to erect the solar panels, and then accomplish sun acquisition.

A trajectory correction maneuver, executed approximately 15 h after injection, provides the spacecraft with a trajectory that terminates at the desired point on the lunar surface and is called the terminal-descent maneuver. This maneuver is computed at the Space Flight Operations Facility from tracking information supplied by the DSIF.

The terminal-descent maneuver is initiated by pointing the vehicle thrust axis in a direction (precalculated at the SFOF) aligned with the predicted velocity vector at main retroignition for vertical approaches. For off-vertical angles, a small bias angle is sometimes introduced. Then, when distance to the lunar surface reaches a preset value (about 60 smi), a pulse-type radar altimeter generates a marking signal. After a suitable time delay, precomputed on earth and preset into the spacecraft flight control subsystem by command, the vernier engines and the main retroengine are ignited.

As the first step in the terminal maneuver, the spacecraft roll axis becomes aligned along the velocity vector. All radars are turned on approximately 5 min before the predicted impact. Following a command enabling signal to the trigger radar, the landing sequence is automatic.

The retroengine separates from the spacecraft after burnout at a nominal lunar altitude of 30,000 ft. Vernier engines then operate under control of the doppler radar and the precision radar altimeter to slow the spacecraft velocity to about 5 ft/s at an approximate altitude of 13 ft, at which time the vernier engines shut off. The solar panel and planar array are unlocked and properly oriented after landing. Postlanding TV sequences are then selected in real-time.

D. Surveyor Spacecraft

1. Design series. The *Surveyor* spacecraft were designed in two basic series. The A-21 series carried an engineering payload to demonstrate successful transit and soft landing, and to gather basic engineering data relative to the performance of the spacecraft in the environments encountered in transit. The collection and transmission of scientific data concerning the lunar surface was a secondary objective for this series. The A-21A series of spacecraft used the same basic soft lunar-landing technology, but carried an additional payload consisting of various scientific instruments. The primary purpose of the A-21A series was the collection and transmission of scientific data relative to the lunar environment.

To ensure a minimum capability of lunar sunrise-to-sunset operations, a minimum predawn operation of 3 h for the A-21 and 20 h for the A-21A spacecraft (nonoperating mode), and a minimum postsunset operation of 150 h (nonoperating mode) were required with a 90-day period of operation as the desired objective.

2. Configuration. The general configuration of the *Surveyors V, VI,* and *VII* spacecraft and identification of its various elements are shown in Fig. 3. The spacecraft were composed of electronic and mechanical assemblies mounted on a basic spaceframe constructed of thin-walled aluminum alloy tubular members. Landing shock was absorbed by a crushable structure and by the tripod landing gear, which also maintained correct attitude after landing.

The equipment carried on the first four missions included flight control, propulsion, telecommunications, TV, and power subsystems. The flight control subsystem provided attitude stabilization and control during all phases of flight. The primary sun sensor and the Canopus sensor provided attitude reference during the coast phases of flight. Other elements of the flight control subsystem included gas jets, an inertial reference unit, and associated electronics. The altitude-marking radar initiated the terminal-descent phase by firing the vernier engines and main retromotor. The radar altimeter and doppler velocity sensor (RADVS) provided signals to control the rate of descent and attitude during the descent phase.

The basic units of the telecommunications subsystem were two transmitters, two transponders, two omnidirectional antennas, and one high-gain planar-array antenna. Additional units provided control and signal processing. The basic functions of the telecommunications subsystem included command reception, transit lunar surface telemetry transmission, and two-way doppler transponder operation.

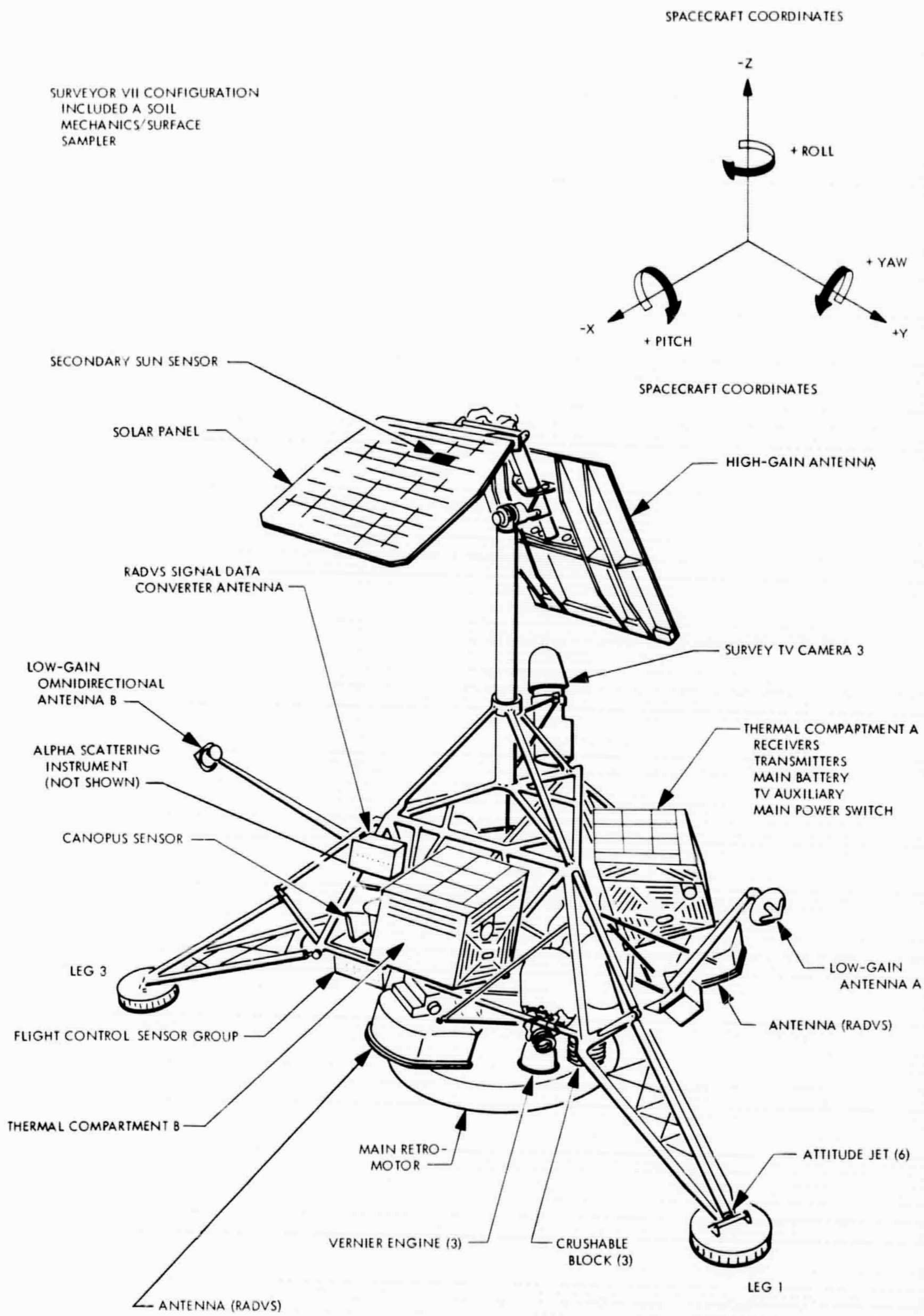


Fig. 3. Sur:eyors V, VI, and VII spacecraft configuration

In addition to these subsystems, the *Surveyor* spacecraft carried an engineering payload. This payload consisted of an auxiliary battery, the television subsystem, accelerometers for measuring vernier engine thrust, strain gages for measuring main retrorocket engine case pressure and touchdown shock, and temperature sensors to measure the thermal status of a variety of components of the system, including the structure. The auxiliary engineering signal processor processed the sensor data for transmission.

The television subsystem consisted of an approach TV camera, a survey TV camera, and additional units to control the cameras. The approach TV camera provided pictures of the lunar landing site from a range of 1000 to approximately 80 mi above the lunar surface. The survey TV camera also provided pictures of selected portions of the lunar surface, of free space, and of the spacecraft after landing.

The *Surveyor* spacecraft had a nominal separated weight of approximately 2200 lb and contained three extendable legs used for stability during touchdown on the lunar surface. The guidance system of each spacecraft maintained full attitude stabilization and directed the spacecraft through maneuvers in attitude and trajectory in response to commands from the ground. Cold gas jets were used to position and maintain the spacecraft in the required attitude. In the stabilized mode, the spacecraft used the sun and Canopus as reference objects.

The spacecraft contained two propulsion systems: a solid-propellant, main retroengine that provided the primary braking during terminal descent, and a variable, low-thrust, liquid-propellant, vernier system capable of executing a midcourse trajectory correction and of providing braking and attitude control during the terminal descent. During the terminal-descent sequence, the propulsion system was controlled automatically by a radar system that measured altitude and velocity components with respect to the lunar surface.

The spacecraft derived their electrical power from solar panels and from batteries for peak power requirements during transit, and after landing during the lunar night. Each had a two-way-communication S-band system that provided a method of telemetering information to the earth, provided command capability to the spacecraft, and provided angle tracking and one- or two-way doppler data for orbit determination.

E. *Atlas/Centaur* Launch Vehicle

The two-stage launch vehicle, shown in Fig. 4, consisted of an *Atlas* first stage and a *Centaur* second stage. Both stages were of a constant 10-ft diameter and used a stainless-steel shell construction that maintained its shape through pressurization without any internal stiffening. All main engines and the *Atlas* vernier engines were gimbaled for directional control. The gross weight of the 105-ft vehicle was approximately 300,000 lb at liftoff.

1. First stage. The first stage of the *Atlas/Centaur* vehicle was a modified version of the *Atlas D* used on many previous NASA and Air Force missions, such as *Ranger, Mariner,* and the *Orbiting Geophysical Laboratory (OGO).* The *Atlas* propulsion system consists of two booster thrust chambers rated at 165,000 lb thrust each, a single sustainer rated at 57,000 lb thrust, and two vernier thrust chambers rated at approximately 1000-lb thrust each. All engines burned a propellant combination of liquid oxygen and RP-1 kerosene that produced a total liftoff thrust of approximately 388,000 lb. The *Atlas* can be considered a 1½-stage vehicle because the booster section, weighing 6000 lb and consisting of the two booster engines together with the booster turbopumps and other equipment located in the aft section, was jettisoned after about 2.5 min of flight. The sustainer and vernier engines continued to burn until propellant depletion. A mercury manometer propellant utilization system was used to control mixture ratio for the purpose of minimizing propellant residuals at *Atlas* burnout.

Flight control of the first stage was accomplished by the *Atlas* autopilot, which contained displacement gyros for attitude reference, rate gyros for response damping, and a programmer to control flight sequencing until *Atlas/Centaur* separation. After booster jettison, the *Atlas* autopilot also was fed steering commands from the all-inertial guidance set located in the *Centaur* stage. Vehicle attitude and steering control were achieved by the coordinated gimbaling of the five thrust chambers in response to autopilot signals.

The *Atlas* contained a single VHF telemetry system that transmitted data on 118 first-stage measurements until *Atlas* separation. The system operated on a frequency of 229.9 MHz over two antennas mounted on opposite sides of the vehicle at the forward ends of the equipment pods. Redundant range-safety command receivers and a single destructor unit were employed on the *Atlas* to provide the range safety officer with means

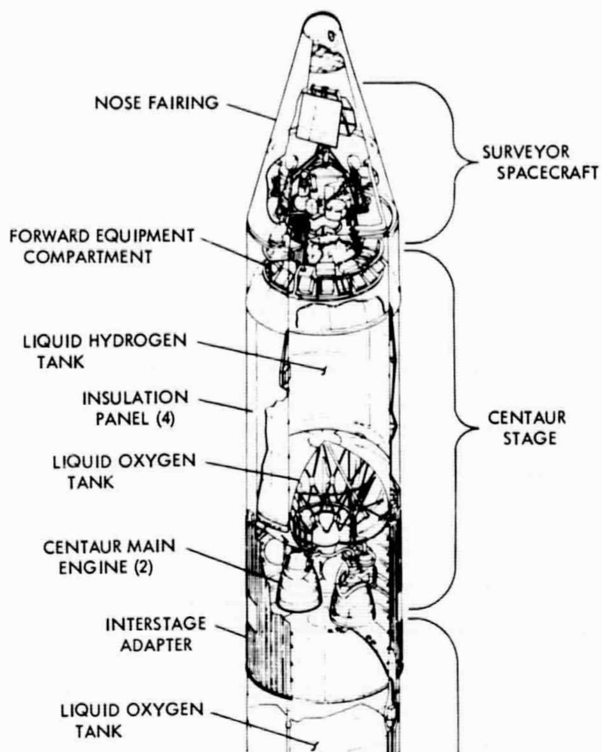


Fig. 4. *Atlas/Centaur/Surveyor* space vehicle configuration

of terminating the flight by initiating engine cutoff and destroying the vehicle. The system was inactive after normal *Atlas* staging occurred. Only the C-band tracking system was used on the *Centaur* stage.

2. Second stage. The *Centaur* second stage was the first vehicle to utilize liquid hydrogen/liquid oxygen, high-specific-impulse propellants. The cryogenic propellants required special insulation to be used for the forward, aft, and intermediate bulkheads, as well as the cylindrical walls of the tanks. The cylindrical tank section was thermally insulated by four jettisonable insulation panels having built-in fairings to accommodate antennas, conduits, and other tank protrusions. The insulation panel hinges were redesigned to overcome a deployment control problem that had been suspected on previous vehicle development flights. Most of the *Centaur* electronic equipment packages were mounted on the forward tank bulkhead in a compartment that was air-conditioned before liftoff.

The *Centaur* was powered by two constant-thrust engines rated at 15,000-lb thrust each at vacuum conditions. Each engine could be gimbaled to provide control in pitch, yaw, and roll. Propellant was fed from each of the tanks to the engines by boost pumps driven with hydrogen peroxide turbines. In addition, each engine contained integral *bootstrap* pumps driven by the hydrogen propellant, which was also used for regenerative cooling of the thrust chambers. A propellant-utilization system was used on the *Centaur* stage to achieve minimum residual of one propellant upon depletion of the other. The system controlled the mixture-ratio valves as a continuous function of propellant in the tanks by means of tank probes and an error-ratio detector. The nominal oxygen/hydrogen mixture ratio was 5:1 by weight.

The second-stage all-inertial guidance system contained an on-board computer that provided vehicle steering commands after jettison of the *Atlas* booster section. The *Centaur* guidance signals were fed to the *Atlas* autopilot until *Atlas* sustainer engine cutoff, and to the *Centaur* autopilot after *Centaur* main engine ignition. *Surveyor I* was the first *Centaur* flight to employ an inertial platform containing new gyros having reduced gimbal stop angles, improved flex leads, better balanced spin motor, and reduced synchronous torque sensitivity. It was also the first flight during which the gyros were not torqued to correct for gyro drift characteristics. Gyro drifts were compensated for by the guidance system computer, which was programmed to set the torquing signals to zero during flight. The *Centaur* autopilot system provided the primary control functions required for vehicle stabilization during powered flight, execution of guidance system steering commands, and attitude orientation following the powered phase of flight. In addition, the autopilot system employed an electromechanical timer to control the sequence of programmed events during the *Centaur* phase of flight, including a series of commands required to be sent to the spacecraft prior to spacecraft separation.

The *Centaur* reaction control system provided thrust to control the vehicle after powered flight. For small corrections in yaw, pitch, and roll attitude control, the system utilized six individually controlled, fixed-axis, constant-thrust, hydrogen peroxide reaction engines. These engines were mounted in clusters of three, 180 deg apart on the periphery of the main propellant tanks at the interstage adapter separation plane. Each cluster contained one 6-lb thrust engine for pitch control and two 3.5-lb thrust engines for yaw and roll control. In addition, four 50-lb thrust hydrogen peroxide engines were installed on the aft bulkhead, with thrust axes parallel with the vehicle axis. These engines were for use during retromaneuver and for executing larger attitude corrections (if necessary). The cluster engines were slightly modified from the design used on previous *Surveyor* flights in that a large aluminum B-nut on the thrust chambers was replaced with a steel flange joint to effect a more positive seal.

The *Centaur* stage utilized a VHF telemetry system with a single antenna transmitting through the nose fairing cylindrical section on a frequency of 225.7 MHz. The telemetry system provided data on 140 measurements from transducers located throughout the second stage and spacecraft interface area, as well as a spacecraft composite signal from the spacecraft central signal processor.

Redundant range safety command receivers were employed on the *Centaur*, together with shaped-charge destruct units for the second stage and spacecraft. This provided the range safety officer with means to terminate the flight by initiating *Centaur* main engine cutoff and destroying the vehicle and spacecraft retrorocket. The system could be safed by a ground command normally transmitted by the range safety officer when the vehicle reached injection energy.

Prior to final encapsulation and mating of *Surveyor*, a system was provided for the automatic destruction of the *Centaur* and spacecraft in the event of premature spacecraft separation.

A C-band tracking system was contained aboard the *Centaur* that included a lightweight transponder, circulator, power divider, and two antennas located under the insulation panels. The C-band radar transponder provided real-time position and velocity data for the range safety instantaneous impact predictor program, as well as data for use in guidance and trajectory analysis.

F. Alpha Scattering Experiment

The *Surveyors V, VI,* and *VII* Missions carried an alpha scattering instrument package. Its function was to determine the chemical composition of the uppermost few microns of the moon's surface by an analysis of the characteristic manner in which nuclei reflect alpha particles. Additional discussion and the operational configuration of this experiment are discussed in Section IV.

II. *Surveyor VII* Mission Synopsis

Surveyor VII was launched from launch complex 36A at Cape Kennedy after a smooth countdown. So that optimum tracking data could be obtained from RIS *Twin Falls,* launch time was rescheduled from 05:55 to 06:30 GMT. Liftoff was accomplished by the *Atlas/Centaur* (AC-15) launch vehicle at 06:30:00.545 GMT on January 7 with a launch azimuth of 102.914 deg. Performance of the *Atlas/Centaur* launch vehicle was excellent through its flight period; all marks occurred very close to predicted mark times.

The transit-through-touchdown phase of the *Surveyor VII* Mission was conducted from January 7 (GMT day 7) through January 10, 1968 (GMT day 10); the spacecraft responded flawlessly to some 335 commands prior to touchdown. First lunar day operations commenced after the successful touchdown and continued through January 26, 1968 at approximately 14:11 PST when all *Surveyor VII* operations were ended. Obtained during the mission were 20,993 good television pictures, 43 h of alpha scattering data, and highly successful soil mechanics/surface sampler operations.

The prime functions of telemetry recovery and command generation were accomplished at the DSN stations. The prime stations were DSS 11 (Pioneer) at Goldstone, Calif.; DSS 42 (Tidbinbilla) at Canberra, Australia; DSS 51 at Johannesburg, South Africa; and DSS 61 (Robledo) at Madrid, Spain. The DSS 14 (Mars) was committed as a backup to DSS 11 during each transit pass and as prime data source during the midcourse and terminal descent phases.

A detailed time-ordered mission profile of the transit phase is tabulated in Table 2. Unless specified otherwise, the times listed are from telemetry data received in the performance analysis area at the SFOF; they include transit time from spacecraft to ground, SFOF processing delay, and commutation delay. Figure 5 shows the *Surveyor VII* flight profile and a summary description of the important mission events. Injection of the *Surveyor* spacecraft occurred at 07:05:15 GMT, after a parking orbit of 1357.8 s, on a trajectory that would have provided a 54.5-km (33.8 mi) miss from the target landing site of 4.95 deg S and 3.88 deg E. Premission planning was to correct, by means of one midcourse correction at $T + 17$ h and possibly one at $T + 48$ h, from this target landing site to an inflight aiming point of 40.87 deg S and 11.37 deg W, which would place *Surveyor VII* on the crater Tycho ejecta blanket. Normal preprogrammed spacecraft events occurred successfully; i.e., high power, landing legs extended, omnidirectional antenna extended, electrical disconnect from *Centaur*, automatic solar panel stepping, antenna/solar panel positioner (A/SPP) roll axis stepping, and automatic sun acquisition, and in the proper order.

Initial DSN acquisition (one-way lock) was accomplished by DSS 42 at approximately 07:21 GMT, and two-way lock was established at 07:27 GMT. Initial spacecraft operations were initiated at 07:31:46.0 GMT by commanding High-Power-OFF. Star verification and acquisition sequence was initiated at 14:24:05 GMT by commanding a sun and roll maneuver. While Canopus was being initially viewed, a maximum signal was obtained in the star intensity channel, but the Canopus lockon signal did not remain on while Canopus was in the field of view. This condition prevented termination of star mapping by use of automatic star acquisition; the use of sun mode and manual lockon was required to obtain Canopus lock. During the star mapping sequence through star intensity signals, Canopus, Caph, and Eta Ursa Majoris, in addition to earth and moon, were observed and tentatively identified. Further evaluation revealed that the signal identified as the star Eta Ursa Majoris was actually the star Mizer.

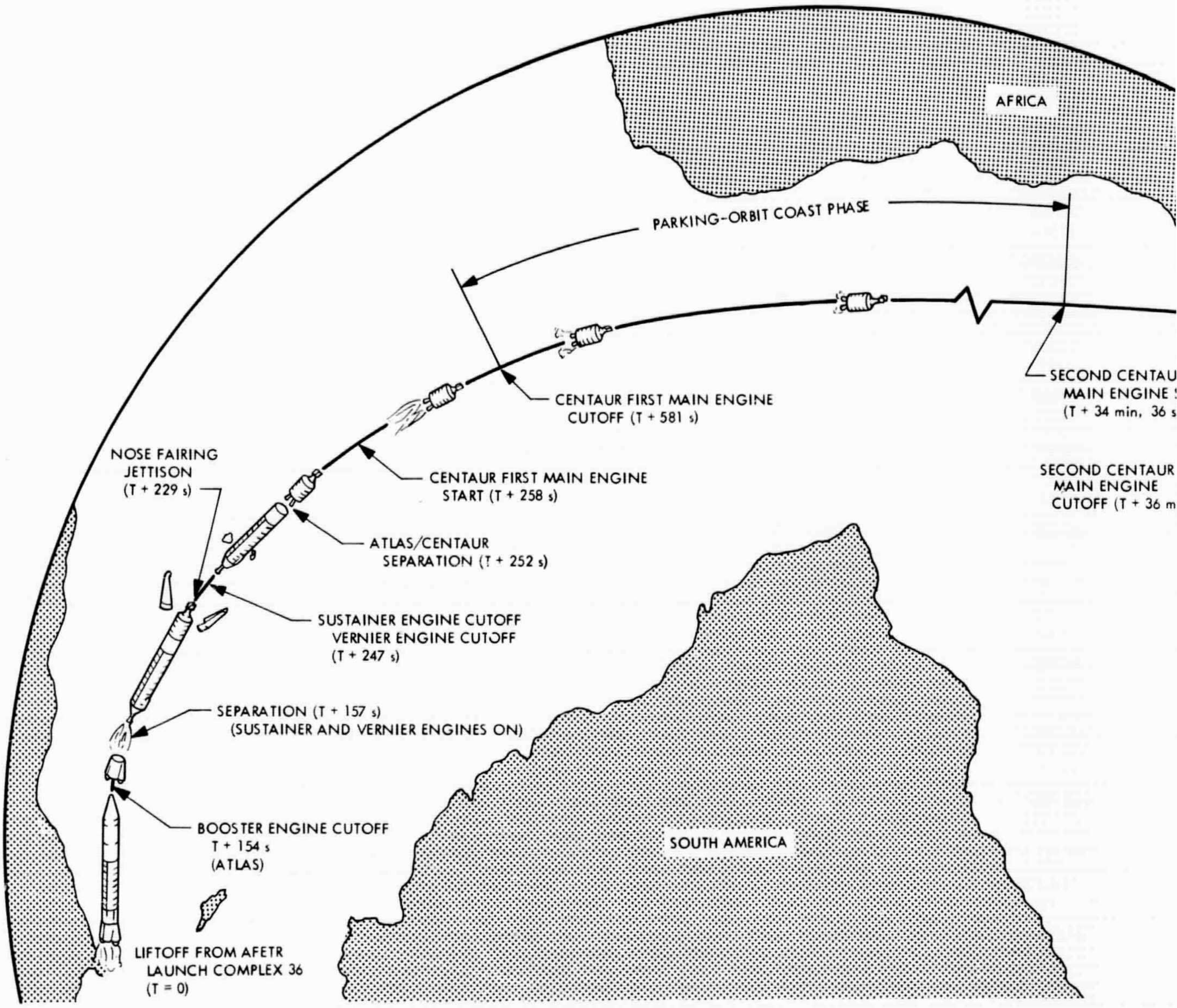
Initial midcourse preparation of the spacecraft was begun at 22:46:40 GMT on day 7 with an engineering interrogation. The spacecraft was configured in high power at 23:03:02 GMT and at 4400 bits/s at 23:20:40 GMT. To reduce possible pointing errors, the technique used on *Surveyors IV*, *V*, and *VI* of initiating the midcourse maneuvers when the respective gyro limit cycle passed through zero was again successfully utilized. The first premidcourse correction maneuver, a negative 3.1-deg roll, was successfully executed at 23:18:28 GMT, followed by a successful positive 117.1-deg yaw at 23:21:13 GMT. The vernier system was pressurized (an anticipated offset of 185 psia was noted) and vernier engine 1 was unlocked at 23:27:47 GMT. Thrust phase power was commanded on at 23:28:39 GMT and the roll actuator null verified. An 11.3-s midcourse velocity correction was loaded and verified at 23:29:21 GMT. At 23:30:09.4 GMT on day 7, the midcourse correction was initiated with a resulting burn of 11.3 s for a change in total spacecraft velocity of 11.08 m/s with 11.05 m/s in the critical plane. The midcourse velocity correction was confirmed by the spacecraft performance analysis and command (SPAC) group. Following midcourse thrust and turnon of cyclic heater loads, the reverse yaw maneuver was commanded at 23:34:10 GMT and successfully completed. Canopus was indicating in the Canopus sensor, and it was elected not to do a reverse roll maneuver. Sun acquisition was indicated at 23:37:43 GMT, and manual star lockon was commanded at 23:41:07 GMT.

Following the initial midcourse maneuvers, the spacecraft bit rate was reduced to 1100 bits/s at 23:48:59 GMT, and low-power operation was established at 23:51:26 GMT on day 7 for the coast phase II configuration.

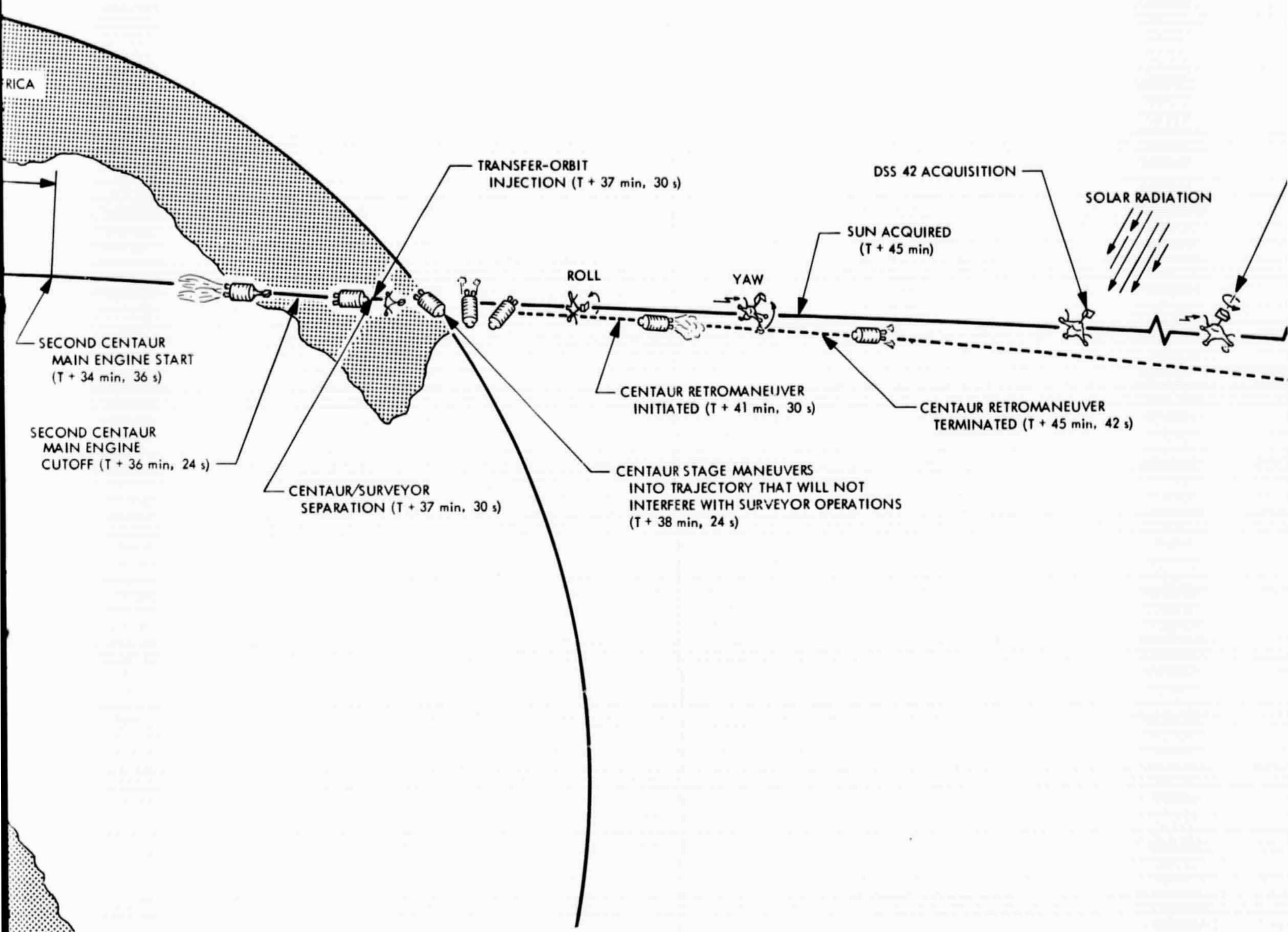
Tracking data obtained after the initial midcourse maneuver indicated that this midcourse correction was extremely successful because there would be a miss of only 2.5 km (1.56 mi) from the inflight aiming point if no second midcourse correction were performed. Postflight analysis indicated a miss of 4.2 km (2.66 mi). Thus, project management elected not to perform a second midcourse correction during coast phase II.

During the entire transit phase, nine gyro drift checks were performed. This number of checks was required to validate and refine the values obtained during the initial gyro drift check. The final gyro drift rates supplied for utilization in terminal maneuver calculations were: (1) roll = +0.65 deg/h, (2) pitch = +0.2 deg/h, and (3) yaw = 0 deg/h.

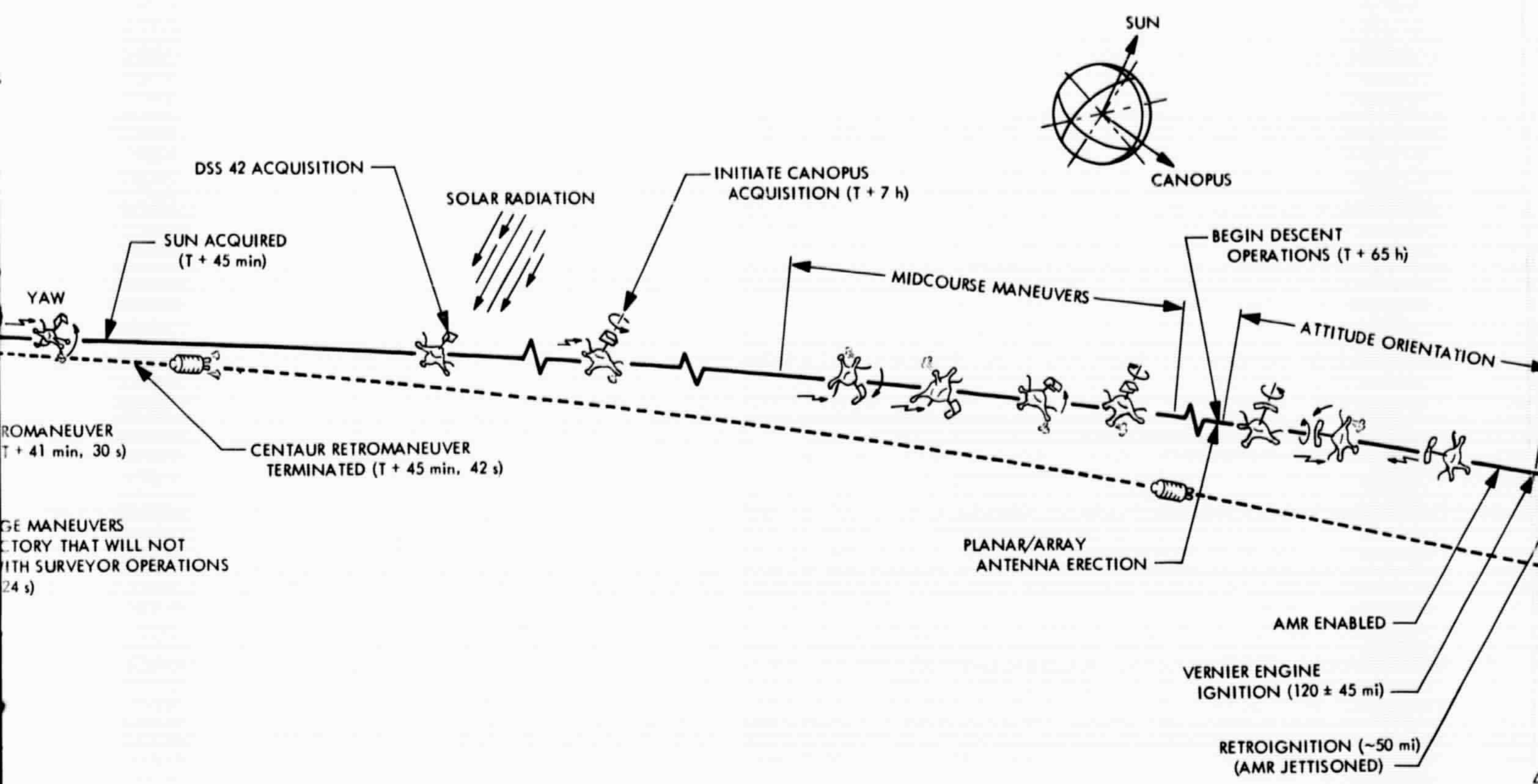
Terminal descent operations were begun during the DSS 11 pass at 22:47:50 GMT on day 11 by initiation of the standard preterminal maneuver interrogation. The spacecraft was commanded to execute and successfully complete the following three terminal maneuvers: (1) plus sun and roll of 80.5 deg, (2) plus yaw of 96.1 deg, and (3) negative roll of 16.5 deg. The respective initiation



FOLDOUT FRAME 1



FOLDOUT FRAME 2



FOLDOUT FRAME 3

FRAME 2

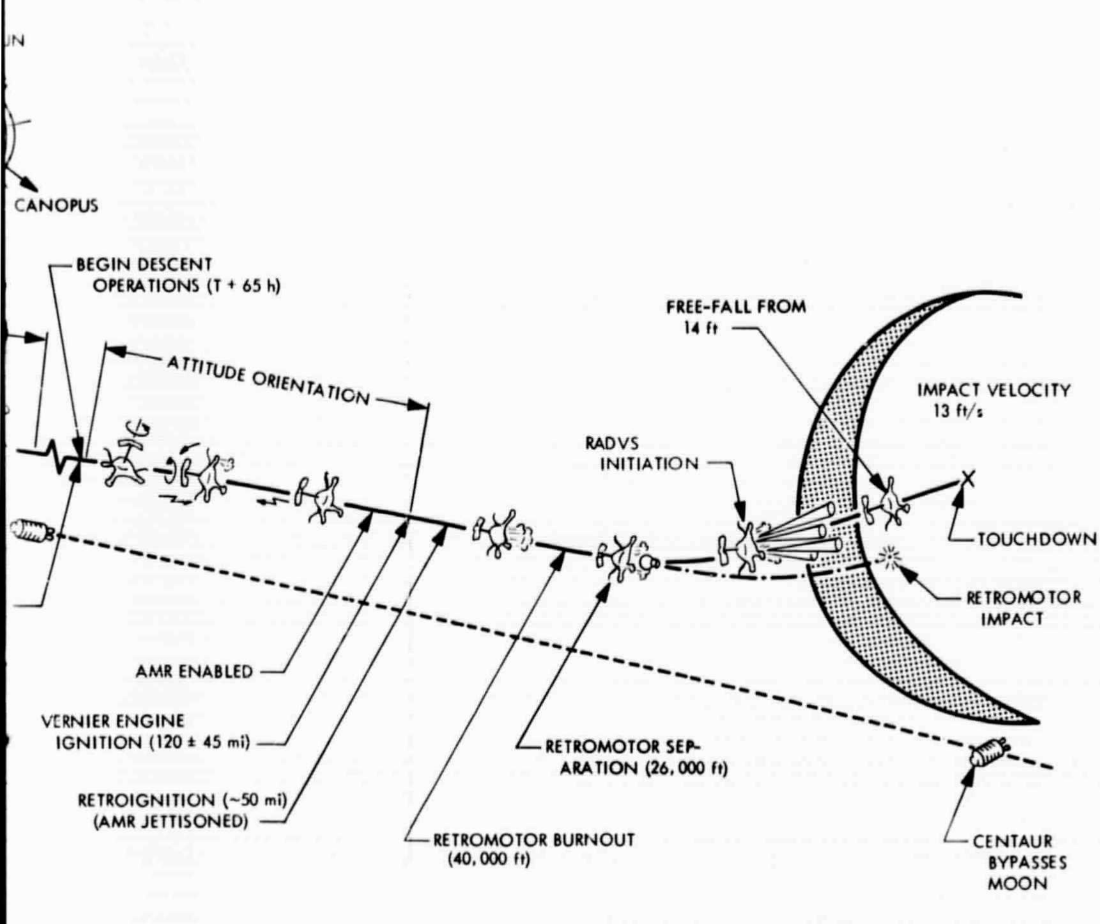


Fig. 5. *Surveyor VII* Mission flight profile

FOLDOUT FRAME 4

times were 00:27:14, 00:35:49, and 00:41:06 GMT on day 10. To obtain touchdown strain gauge data, phase modulation presumming amplifiers were commanded on at 00:42:32 GMT. At that time, the DSS received carrier power at DSS 11 was −125.9 dBmW, well within the turnon criteria for a minimum received carrier power of −127.6 dBmW at either DSS 11 or DSS 14. A retromotor sequence delay of 2.775 s was loaded and verified at 00:56:11 GMT on day 11, followed by thrust phase power on at 00:58:33 GMT. The automatic marking radar (AMR) was enabled at 01:00:33 GMT, and the emergency AMR signal was transmitted at 01:02:13 GMT. The AMR mark occurred at 01:02:10.6 GMT, followed by vernier ignition at 01:02:13.36. The remainder of the automatic portion of the terminal descent sequence was implemented by the spacecraft in a nominal manner. Touchdown occurred at 01:05:36.337 GMT on day 10; the spacecraft signal was maintained by DSS 11 throughout the landing sequence, indicating that the spacecraft landed upright and undamaged. Landing legs 1, 3, and 2 contacted the lunar surface in that order. The contact forces were 1650 lb for leg 1, 1420 lb for leg 3, and 1700 lb for leg 2; the touchdown velocity was 13 ft/s.

The TDS support for the *Surveyor VII* Mission was considered good. The minor problems experienced by elements of the TDS did not impact the overall support. All requirements were met and in most cases exceeded.

Table 2. *Surveyor VII* Mission profile

Time		Command sequence		Event
After launch	GMT	Major	Minor	
Launch to separation				
0	06:30:00.545 Jan 7, 1968			Launch
00:34:35	07:04:37			Extend Landing Gears commanded by *Centaur*
00:34:43	07:04:45			Extend Omniantennas commanded by *Centaur*
00:34:59	07:05:00			Transmitter High Voltage On commanded by *Centaur*
				Spacecraft/*Centaur* electrical disconnect
00:35:15	07:05:16			Separation
00:40:37	07:10:38			Solar panel locked in transit position
00:43:33	07:13:34			Sun acquisition cell illuminated (after 225-deg roll)
00:44:29	07:14:30			Sun lockon achieved (primary sun sensor cell illuminated after 43-deg yaw)
00:44:28	07:14:29			Roll axis locked in transit position
00:57:54	07:27:55			Initial DSIF acquisition completed (two-way lock)
DSIF acquisition through star acquisition				
01:01:46	07:31:47	0040	0552	Turn off spacecraft high power transmitter
01:04:45	07:34:46	0040	0050	Turn off analog-to-digital isolation amplifier and solar panel deployment logic
01:06:13	07:36:14	0040	0454	Rocking solar panel back and forth to seat locking pin
01:07:48	07:37:49	0040	0455	Rocking roll axis back and forth to seat locking pin
01:08:44	07:38:45	0040	0051	Mode 1 interrogation
01:10:04	07:40:05	0040	0052	Initial/100 bits/s selection (change from 550 bits/s low modulation index)
01:12:26	07:42:27	0040	0055	Mode 4 interrogation
01:15:12	07:45:13	0040	0251	Mode 2 interrogation
01:17:47	07:47:48	0040	1356	Mode 6 interrogation
01:19:55	07:49:56	0040	1354	Return to mode 5 for coast phase monitoring
04:06:14	10:36:15		11E1	Mode 1 interrogation

Table 2 (contd)

Time		Command sequence		Event
After launch	GMT	Major	Minor	
DSIF acquisition through star acquisition (contd)				
04:08:19	10:38:20		11A2	Mode 2 interrogation
04:10:11	10:40:12		11B4	Mode 4 interrogation
04:11:59	10:42:00		11D5	Return to mode 5 for coast phase monitoring
05:57:47	12:27:48			Solar panel switch commanded on
06:16:01	12:46:02			Solar panel switch commanded on
07:36:31	14:06:32	0046	0250	Start of prestar verification engineering interrogation
07:36:31	14:06:32	0046	0250	Mode 4 interrogation
07:40:30	14:10:31	0046	0251	Mode 2 interrogation
07:42:03	14:12:04	0046	0252	Mode 1 interrogation
	14:15:22			Command 0000
07:46:16	14:16:17	0041	0652	Transmitter filament turn on
07:47:54	14:17:55			Solar panel switch commanded on
07:48:26	14:18:27	0041	0653	Transmitter high voltage turn on
07:49:08	14:19:09	0041	0253	Selection of 4400 bits/s
07:51:19	14:21:20	0041	1050	Transponder power off
07:52:16	14:22:17	0041	0654	Manual delay mode and positive angle maneuver commanded
07:54:04	14:24:05	0041	1251	Start of roll
08:14:58	14:44:59			Sun mode commanded to stop roll maneuver
08:17:31	14:47:32			Manual lockon commanded to cause Canopus lockon
08:19:58	14:49:59	0041	0550	Mode 5 selected
08:21:03	14:51:04	0041	1053	Transponder B turned on
08:26:44	14:56:45	0041	0150	Bit rate reduction from 4400 to 1100 bits/s
08:27:55	14:57:56	0041	0552	Turn off transmitter high power
Coast phase I				
09:06:01	15:36:02	0041	0354	Initiate gyro drift check 1, three-axis
10:00:31	16:30:32	0041	0250	Mode 4 interrogation
10:05:42	16:35:43	0041	0251	Mode 2 interrogation
10:09:04	16:39:05	0041	0252	Mode 1 interrogation
10:12:57	16:42:58	0041	0550	Return to mode 5
11:01:27	17:31:28	0041	0054	Terminate gyro drift check by commanding cruise mode and manual lockon
11:06:31	17:36:32		0354	Initiate gyro drift check 2, three-axis
11:07:09	17:37:10		0306	Solar panel switch commanded on
11:53:12	18:23:13		0250	Mode 4 interrogation
12:01:25	18:31:26	0046	0251	Mode 2 interrogation
12:05:53	18:35:54	0046	0252	Mode 1 interrogation
12:08:39	18:38:40	0046	0550	Return to mode 5
12:39:42	19:09:43			Terminate gyro drift check by commanding cruise mode and manual lockon
14:57:18	21:27:19	0042	0250	Initiate premidcourse interrogation
14:57:18	21:27:19	0042	0250	Mode 4 interrogation
15:05:50	21:35:51	0042	0251	Mode 2 interrogation
15:09:36	21:39:37	0042	0252	Mode 1 interrogation
15:13:06	21:43:07	0042	0550	Return to mode 5

Table 2 (contd)

Time		Command sequence		Event
After launch	GMT	Major	Minor	
Midcourse correction				
15:15:01	21:45:02	0042	0350	Initiate gyro speed check
15:16:10	21:46:11	0042	0351	Select next gyro three times
15:19:06	21:49:07	0042	0352	Gyro speed signal processing off and return to mode 5
16:16:39	22:46:40	0043	0250	Initiate midcourse correction interrogation
16:16:39	22:46:40	0043	0250	Mode 4 interrogation
16:18:56	22:48:57	0043	0251	Mode 2 interrogation
16:21:07	22:51:08	0043	0252	Mode 1 interrogation
16:27:32	22:57:33	0043	0652	Transmitter filament turnon
16:32:01	23:02:02	0043	0653	Transmitter high power turnon
16:32:39	23:02:40	0043	0253	Increase bit rate from 550 to 4400 bits/s
16:38:04	23:08:05	0403	1150	Command desired roll maneuver magnitude and direction (roll −3.1 deg)
16:48:27	23:18:28	0403	1251	Start of roll near zero crossing of Canopus error signal
16:49:00	23:19:01	0403	1155	Command desired yaw maneuver magnitude and direction (yaw +117.1 deg)
16:51:12	23:21:13	0403	1253	Start of yaw near zero crossing of primary sun sensor yaw error signal
16:56:46	23:26:47	0403	0751	Propulsion strain gauge powered, inertial mode, and reset group IV outputs commanded
16:57:44	23:27:45	0403	0750	Turn off cyclic loads, AMR, vernier line heaters
16:57:47	23:27:48	0740	0750	Pressurize vernier system (helium) unlock vernier engine 1
16:58:38	23:28:39	0043	0752	Thrust phase power on
16:59:20	23:29:21	0043	0753	Command desired thrust duration (11.35 s)
17:00:08	23:30:09	0043	0754	Execute midcourse thrust
17:00:22	23:30:23	0043	0754	Command terminate thrust
17:00:42	23:30:43	0043	0754	Turn off thrust phase power
17:01:02	23:31:03	0043	0754	Turn off propulsion strain gauge power
17:01:33	23:31:34	0043	0550	Operations to obtain coast mode data
17:02:33	23:32:34	0043	0755	Cyclic loads turned on. Vernier line, AMR heaters
17:03:29	23:33:30	0043	1252	Command reverse yaw maneuver magnitude and direction (−117.1 deg)
17:04:10	23:34:11	0043	1253	Execute yaw (sun reacquired at 23:37:25 GMT)
17:10:38	23:40:39		0054	Cruise mode commanded
17:11:07	23:41:08			Manual lockon sun and star commanded
17:13:31	23:43:32	0043	0157	Mode 2 interrogation
17:15:39	23:45:40	0043	0055	Mode 4 interrogation
17:18:07	23:48:08	0043	0550	Return to mode 5
17:18:58	23:48:59	0043	0150	Reduce bit rate from 4400 to 1100 bits/s
17:21:18	23:51:19	0043	0552	Turn off transmitter high power
Coast phase II				
	(Jan 8, 1968)			
17:34:11	00:04:12			Initiate gyro drift check 3, three-axis
19:01:55	01:31:56		0250	Mode 4 interrogation

Table 2 (contd)

Time		Command sequence		Event
After launch	GMT	Major	Minor	
Coast phase II (contd)				
19:07:26	01:35:25		0251	Mode 2 interrogation
19:05:24	01:37:27		0252	Mode 1 interrogation
19:10:59	01:41:00		0550	Return to mode 5
20:12:57	02:42:58			Terminate gyro drift check by commanding cruise mode and manual lockon
20:18:54	02:48:55		0354	Initiate gyro drift check 4, roll only
23:32:41	06:02:42			Terminate gyro drift check by commanding manual lockon
23:36:22	06:06:23		0354	Initiate gyro drift check 5, three-axis
24:18:45	06:48:46		0250	Mode 4 interrogation
24:21:02	06:51:03		0251	Mode 2 interrogation
24:24:25	06:54:26		0252	Mode 1 interrogation
24:26:09	06:56:10		0550	Return to mode 5
26:06:49	08:36:50			Terminate gyro drift check by commanding cruise mode and manual lockon
29:22:03	11:52:04		0250	Mode 4 interrogation
29:25:48	11:55:49		0251	Mode 2 interrogation
29:30:23	12:00:24		0252	Mode 1 interrogation
29:33:44	12:03:45		0550	Return to mode 5
31:32:21	14:02:22		0354	Initiate gyro drift check 6, three-axis
33:30:36	16:00:37		0250	Mode 4 interrogation
33:05:58	16:05:59		0251	Mode 2 interrogation
33:39:08	16:09:09		0252	Mode 1 interrogation
33:43:15	16:13:16		0550	Return to mode 5
34:44:32	17:14:33			Terminate gyro drift check by commanding cruise mode and manual lockon
36:39:41	19:09:42	0046	0250	Mode 4 interrogation
36:43:24	19:13:25	0046	0251	Mode 2 interrogation
36:47:47	19:17:48	0046	0252	Mode 1 interrogation
36:22:49	19:23:50	0046	0550	Return to mode 5
37:34:57	20:04:58			Vernier oxidizer tank 2 temperature control commanded on
39:25:27	21:55:28	0046	0250	Mode 4 interrogation
39:28:02	21:58:03	0046	0251	Mode 2 interrogation
39:29:55	21:59:56	0046	0252	Mode 1 interrogation
39:31:36	22:01:37	0046	0550	Return to mode 5
	(Jan 9, 1968)			
42:49:28	01:19:29	0046	0250	Mode 4 interrogation
42:51:49	01:21:50	0046	0251	Mode 2 interrogation
42:53:59	01:24:00	0046	0252	Mode 1 interrogation
42:56:11	01:26:12	0046	0550	Return to mode 5
44:35:44	03:05:45	0046	0354	Initiate gyro drift check 7, three-axis
47:04:23	05:34:24			Terminate gyro drift check by commanding cruise mode and manual lockon
47:41:35	06:11:36	0046	0250	Mode 4 interrogation
47:44:10	06:14:11	0046	0251	Mode 2 interrogation

Table 2 (contd)

Time		Command sequence		Event
After launch	GMT	Major	Minor	
Coast phase II (contd)				
47:46:44	06:16:45	0046	0252	Mode 1 interrogation
47:49:08	06:19:09	0046	0550	Return to mode 5
48:46:23	07:16:24		0354	Initiate gyro drift check 8, three-axis
51:18:31	09:48:32			Terminate gyro drift check by commanding cruise mode and manual lockon
52:29:40	10:59:41		0250	Mode 4 interrogation
52:36:17	11:06:18		0251	Mode 2 interrogation
52:39:14	11:09:15		0252	Mode 1 interrogation
52:42:23	11:12:24		0550	Return to mode 5
55:19:42	13:49:43			Command 3737 repeated twice
55:30:05	14:00:06		0357	Initiate gyro drift check 9, three-axis
55:30:20	14:00:21		3054	Compartment A thermal control commanded on
55:44:00	14:14:01		0250	Mode 4 interrogation
55:48:23	14:18:24		0251	Mode 2 interrogation
55:51:55	14:21:56		0252	Mode 1 interrogation
55:54:40	14:24:41		0550	Return to mode 5
58:34:12	17:04:13			Terminate gyro drift check by commanding cruise mode and manual lockon
59:36:50	18:06:51	0046	0250	Mode 4 interrogation
59:41:09	18:11:10	0046	0251	Mode 2 interrogation
59:44:37	18:14:38	0046	0252	Mode 1 interrogation
59:49:11	18:19:12	0046	0550	Return to mode 5
59:49:45	18:19:46	0046	1757	Survey television electronics thermal control on
61:25:15	19:55:16		0151	Reduce bit rate from 1100 to 550 bits/s
62:28:08	20:58:09	0046	0250	Mode 4 interrogation
62:33:38	21:03:39	0046	0251	Mode 2 interrogation
62:35:22	21:05:23	0046	0252	Mode 1 interrogation
62:37:44	21:07:45	0046	0550	Return to mode 5
63:57:23	22:27:24		3056	Compartment C thermal control on
64:01:59	22:32:00		3056	Alpha scattering heater power on
64:14:03	22:44:04		3054	Compartment A heater off
64:17:49	22:47:50	0046	0250	Mode 4 interrogation
64:19:47	22:49:48	0046	0251	Mode 2 interrogation
64:23:03	22:53:04	0046	0252	Mode 1 interrogation
64:27:59	22:58:00	0046	0550	Return to mode 5
64:29:16	22:59:17	0046	0350	Initiate gyro speed check
64:30:07	23:00:08	0046	0351	Select next gyro three times
64:31:51	23:01:52	0046	0352	Return to mode 5
64:34:25	23:04:26	0046	1050 1053	Narrow-band voltage-controlled crystal oscillator check
65:24:47	23:54:48	0044	1757	Vidicon temperature control on
Terminal descent				
65:29:10	23:59:11	0044	1355	Mode 6 interrogation
	(Jan 10, 1968)			
65:31:17	00:01:18	0044	0250	Mode 4 interrogation

Table 2 (contd)

Time		Command sequence		Event
After launch	GMT	Major	Minor	
Terminal descent (contd)				
65:33:11	00:03:12	0044	0652	Transmitter filament turnon
65:35:54	00:05:55	0044	0653	Transmitter high power, commands repeated twice
65:38:01	00:08:02	0044	0255	Increase bit rate from 550 to 1100 bits/s
65:38:41	00:08:42	0044	2057	Presumming amplifier off
65:39:12	00:09:13	0044	0251	Mode 2 interrogation
65:41:31	00:11:32	0044	0550	Return to mode 5, commands sent twice
65:48:28	00:18:29	0044	1755	Propulsion strain gauge power turned on
65:49:02	00:19:03	0044	1756	Touchdown strain gauge power and subcarrier oscillators turned on
65:51:14	00:21:15	0044	1050	Transponder power commanded off twice and one-way lock achieved
65:52:55	00:22:56	0044	1154	Roll maneuver magnitude and direction commanded (+80.5 deg)
65:57:13	00:27:14	0044	1251	Execute sun and roll at Canopus error signal null
66:00:28	00:30:29	0044	1155	Yaw magnitude and direction command (+96.1 deg)
66:05:49	00:35:50	0044	1253	Execute yaw at primary sun sensor yaw error null (retrothrust direction aligned properly at approximately 00:39:05 GMT)
66:09:44	00:39:45	0044	1157	Roll maneuver magnitude and direction commanded (−16.5 deg)
66:11:06	00:41:07	0044	1257	Roll executed
66:12:32	00:42:33	0044	2152	Presumming amplifier on commanded (to get touchdown strain gauge data)
66:13:38	00:43:39	0044	1751, 1656	Vernier thrust level (200 lb) for retro phase and delay between AMR mark and vernier ignition (2.775 s) commanded
66:20:09	00:50:10	0044	1355	Command on mode 6 data
66:20:54	00:50:55		1652	Command reset group IV outputs
66:26:10	00:56:11	0044	1657	Retro sequence mode on commanded
66:26:25	00:56:26	0044	1752	Vernier lines and tanks, alpha scattering, television, and AMR thermal control commanded off
66:27:33	00:57:34	0044	1753	AMR on
66:28:33	00:58:34	0044	1754	Thrust phase power on
66:30:33	01:00:34	0044	2051	AMR enabled
66:32:12	01:02:13	0044	2051	Backup AMR *mark* commanded
66:32:11.385	01:02:11.930[a]			AMR *mark*
66:32:14.185	01:02:14.730[a]			Vernier ignition
66:32:15.285	01:02:15.830[a]			Retroignition
66:32:15.795	01:02:16.340[a]			RADVS on
66:32:17.695	01:02:18.240[a]			Inertia switch off
66:32:48.894	01:02:49.439[a]			Reliable-operate doppler velocity sensor
66:32:49.094	01:02:49.639[a]			Reliable-operate radar altimeter
66:32:58.483	01:02:59.028[a]			Retroburnout

[a]Based on reduced data obtained directly from the 96-kHz microwave link data (1.21 s must be subtracted to account for RF propagation).

Table 2 (contd)

Time		Command sequence		Event
After launch	GMT	Major	Minor	
Terminal descent (contd)				
66.32.58.493	01:02:59.038[a]			Inertia switch on
66:33:08.483	01:03:09.028[b]			High thrust on
66:33:10.483	01:03:11.028[a]			Retroeject
66:34:27.880	01:05:13.323[a]			1000-ft mark
66:35:29.678	01:05:30.223[a]			10-ft/s mark
66:35:25.777	01:05:36.322[a]			13-ft mark
66:35:37.075	01:05:37.620[a]			Touchdown

[a]Based on reduced data obtained directly from the 96-kHz microwave link data (1.21 s must be subtracted to account for RF propagation).
[b]Extrapolated from burnout.

III. *Surveyor VII* TDS Mission Requirements

A. General

Delineated in this section are the detailed requirements and support capabilities for tracking and telemetry coverage of the *Atlas/Centaur/Surveyor VII* space vehicle.

Requirements for tracking and data acquisition are placed in accordance with their importance to the successful accomplishment of the mission and are grouped into three classes. These classes are defined as follows:

(1) Class I requirements reflect minimum essential needs to ensure accomplishment of the primary flight objectives. These are mandatory requirements which if not met may result in the decision not to launch.

(2) Class II requirements define the needs to accomplish all stated flight objectives.

(3) Class III requirements define the ultimate desired support. Such support should enable the project to achieve the flight objectives early in the program.

The AFETR, MSFN, and DSN elements of the TDS were required to support tracking and telemetry requirements during the near-earth phase (launch to $T + 4$ h) so that timely and continuing evaluation of the status of the mission could be obtained. This early evaluation was used to aid in maximizing the probability of acquisition by the Deep Space Stations and to provide information for the conduct of subsequent space flight operations.

The following requirements were placed on the TDS for the *Surveyor VII* Mission:

1. Launch. The launch requirements were as follows:

(1) The *Atlas/Centaur* boost vehicle will be utilized in a parking orbit mode of operation for *Surveyor VII*.

(2) Launch shall take place from launch complex 36A of the Cape Kennedy facilities for the AFETR.

(3) Launch azimuth sectors are restricted to lie between 78 and 115 deg east of true north.

(4) The launch countdown shall have two built-in holds, one of at least 60-min duration at $T - 90$ min. The duration of the hold at $T - 5$ min is to be established.

2. Preinjection. Requirements for the preinjection period included:

(1) The nominal parking orbit altitude shall be 90 nmi.

(2) The nose fairing shall be ejected prior to injection, but not until the value of the product of the atmospheric density and the earth-fixed velocity cubed (ρV^3) is less than 1.9×10^4 lb/s^3.

(3) During the period beginning 1 min after shroud ejection and ending at the time of *Centaur* second main engine start (MES 2), the instantaneous 3-σ value of the aerodynamic heating parameter, ρV^3, shall not exceed 2050 lb/s^3.

(4) Throughout the period from MES 2 until the end of significant aerodynamic heating effects, the 3-σ integrated value of ρV^3 shall not exceed 10,300 lb-min/s^3, and the instantaneous 3-σ value shall not exceed 4250 lb/s^3.

(5) Parking orbit coast time is restricted to vary between the limits of 116 s and 25 min.

3. Postinjection. The *Centaur* retromaneuver shall be such that the *Surveyor/Centaur* separation distance at 5 h after injection will be at least 336 km.

4. Telecommunications. Telecommunications requirements were as follows:

(1) No trajectory shall have an hour angle or declination rate in excess of 0.85 deg/s and acceleration in either hour angle or declination in excess of 5.0 deg/s^2 when station tracking is required.

(2) For the downlink initial acquisition phase following injection, there shall be 20 min of visibility which is not in violation of item (1) and for which the spacecraft slant range ensures at least 95% confidence of having the antenna gain required for zero minimum margin.

(3) For the uplink acquisition phase following injection, there shall be 20 min of visibility which is not in violation of item (1) and for which the spacecraft slant range ensures at least 99% confidence of having the antenna gain required for zero minimum margin.

(4) The spacecraft-centered angle between the sun and any DSIF station shall not exceed 175 deg in order to prevent the degradation of DSIF receiver sensitivity by solar noise. This constraint guarantees that signal-to-noise ratios will not be degraded by more than 1 dB.

(5) The DSS 14 (the 210-ft antenna at the Goldstone Mars station) is required for telemetry acquisition during the terminal descent phase.

5. Thermal control. Requirements for thermal control were:

(1) The spacecraft is limited to a maximum duration of 42 min in the shadow of the earth immediately after launch.

(2) The spacecraft is limited to a maximum duration of 30 min in the shadow of the earth during any phase after initial sun acquisition.

(3) The spacecraft is limited to a maximum duration of 30 min at a random attitude to the sun during any phase between initial sun acquisition and lunar touchdown.

(4) The spacecraft is limited to a maximum duration of 30 min in the lunar penumbra during any phase prior to touchdown.

(5) Initial spacecraft acquisition and the establishment of a command link must take place no later than 1 h after High-Power-On command to permit switching the transmitter from high to low power to satisfy thermal constraints.

6. Midcourse maneuver. The spacecraft shall be capable of performing midcourse maneuvers of up to 40 m/s in magnitude. Nominal first midcourse maneuver time is approximately 15–20 h after launch. Landing accuracy goal shall be less than or equal to 10 km.

7. Lunar arrival. Lunar arrival requirements were the following:

(1) Flight times from injection to lunar impact shall be in the 66-h class.

(2) Transit trajectories are to be designed so that lunar arrival takes place not earlier than 2 h after DSS 11 (Goldstone, Pioneer station) moon rise and not later than 3 h before DSS 11 moon set.* Furthermore, DSS 11 postlanding visibility shall be maximized.

(3) It is desirable that landing occur before the sun elevation angle has exceeded 25 deg at the landing site.

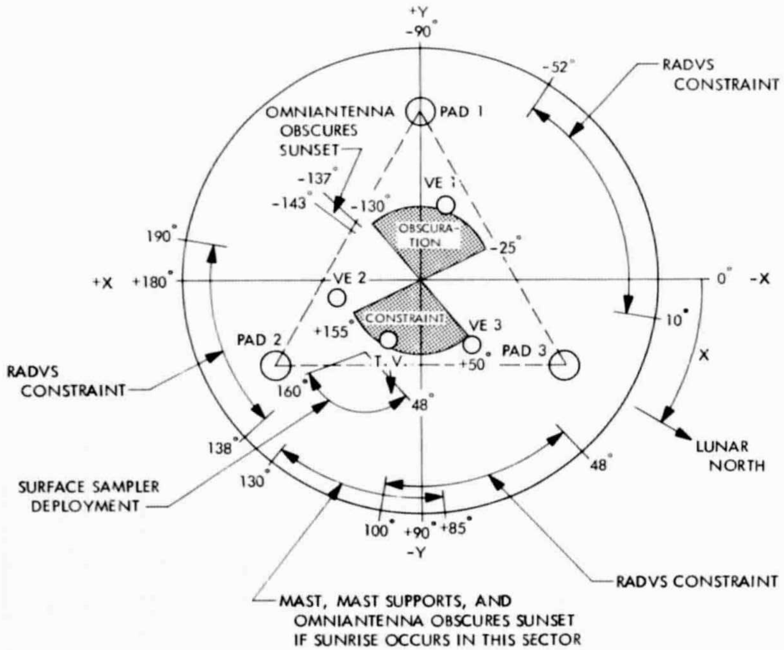
8. Terminal descent. The requirements during terminal descent were as follows:

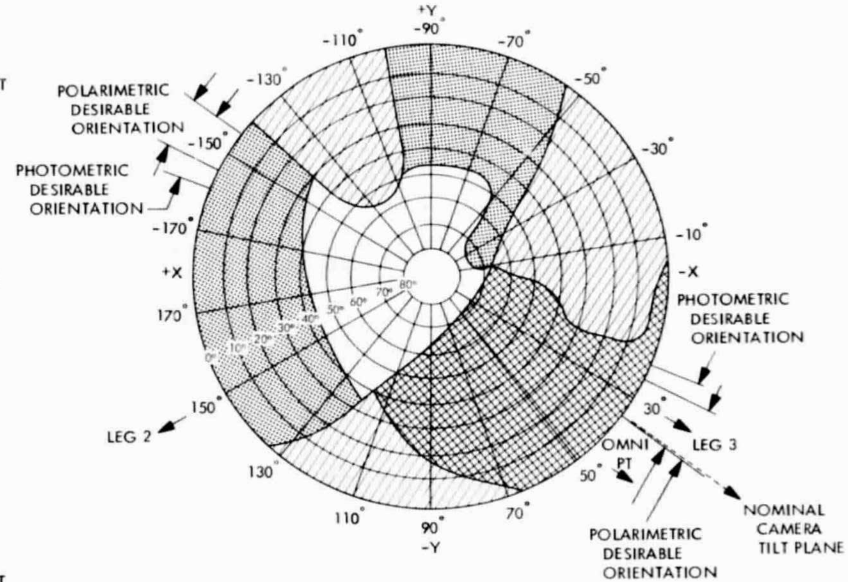
(1) The incidence angle at unbraked impact shall not be greater than 45 deg from the vertical.

(2) The nominal unbraked impact speed is 2660 m/s.

(3) The spacecraft roll orientation constraints are given in Fig. 6. The RADVS constraints shown graphically apply only to the January 7 launch date. The actual constraint regions for each launch date are presented in the accompanying table. The selected roll orientation is also shown in a table in Fig. 6.

*These constraints applied only to targeting. The visibility constraints used at midcourse were: earliest arrival, 80 min after DSS 11 rise; latest arrival, 3 h before DSS 11 set.





SURVEYOR VII STABILITY CONSTRAINTS NEED NOT BE CONSIDERED DUE TO NEGLIGIBLE PROBABILITY OF NOMINAL BURNOUT VELOCITY EXCEEDING 500 ft/s

RADVS CONSTRAINTS SHOWN IN LEFT-HAND DIAGRAM REFER ONLY TO JANUARY 7. THOSE FOR ALL DAYS ARE LISTED IN TABLE BELOW DIAGRAM

BOTH OMNIANTENNAS AND LEG PHOTOMETRIC TARGETS IN SHADOW

LEG PHOTOMETRIC TARGET IN SHADOW

OMNIANTENNA PHOTOMETRIC TARGET IN SHADOW

SURVEYOR VII RADVS CONSTRAINT REGIONS

LAUNCH DATE	UNACCEPTABLE SUN AZIMUTH AT TYCHO, deg		
JAN 7	-52 to 10	48 to 100	138 to 190
JAN 8	-56 to 5	44 to 95	134 to 185
JAN 9	-63 to -2	37 to 88	127 to 178
JAN 10	-71 to -10	29 to 80	119 to 170
JAN 11	-82 to -21	18 to 69	108 to 159
JAN 12	-96 to -35	4 to 55	94 to 145

SELECTED LANDED ROLL ORIENTATION FOR TYCHO LANDING SITE

LAUNCH DATE	SUN AZIMUTH, deg	X, deg
JAN 7	196	115
JAN 8	191	118
JAN 9	184	121
JAN 10	176	125
JAN 11	165	129
JAN 12	151	133

Fig. 6. *Surveyor VII* roll angle constraints, sun azimuth at landing

9. Surveyor missions relationship. One of the prime project objectives for earlier *Surveyors* (*I–VI*) was to provide basic data in support of the *Apollo* Project. The potential *Apollo* landing sites are contained in the area bounded by ±45 deg in longitude and ±5 deg in latitude as shown by the heavy black lines in Fig. 7. The landing site for each previously successful *Surveyor* spacecraft is also indicated in Fig. 7.

The successful completion of the *Surveyor VI* Mission terminated the obligation to investigate potential *Apollo* landing sites. Thus, the prime project objective for *Surveyor VII,* the last of the scheduled *Surveyor* missions, was that of obtaining the maximum scientific value from the mission. It was concluded that the scientific value can be maximized by landing at a site which offers the greatest chemical diversity from what has been analyzed in the maria, i.e., entirely different material to look at from previous landings. Based upon this objective, the prime landing site selected (11.37 deg W, 40.87 deg S) was just north of the crater Tycho and within the area designated as the Tycho ejecta blanket. This site location is included in Fig. 7 for comparison with previous landing site locations. Specifically, the scientific advantages of the Tycho site were that it:

(1) Offers the best chance of providing a sample of highland material.

(2) Is possibly the youngest large crater on the front side of the moon.

(3) Lies well within the highland region and is far removed from mare material.

(4) Is a fresh feature which is likely to be relatively free from contamination by material from other parts of the moon.

(5) Is an outstanding anomaly in radar reflection.

(6) Is one of the outstanding anomalies in the infrared.

(7) Is a very young area with the least number of craters of any part of the moon.

If it is determined in flight that the probability of landing at the Tycho site is not within a reasonable

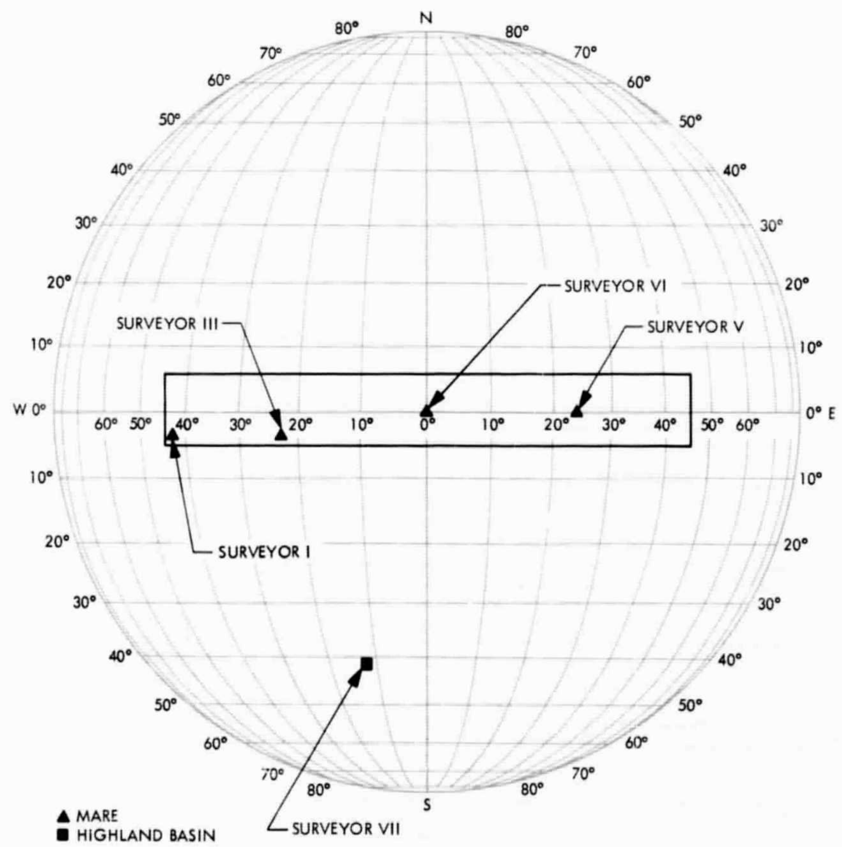


Fig. 7. Surveyor mission success profile

accuracy, the *Surveyor* spacecraft will be directed to a secondary landing site. This site (17.50 deg W, 3.75 deg S) lies in the Fra Mauro formation north of the crater Fra Mauro in rolling terrain which is on the outer perimeter of a broad belt encompassing the Imbrian Basin. This area promises to provide a sample of material excavated from many tens of kilometers beneath the lunar surface, possibly of sub-crustal material. The surface texture is expected to be similar to the mare but the chemistry should be significantly different.

The *Surveyor VII* scientific experiments include survey TV, an alpha scattering experiment identical to the one on *Surveyor VI* and a surface sampler. The alpha scattering instrument (Fig. 8) is intended to perform compositional (elemental) analysis of the lunar surface material.

B. Air Force Eastern Test Range

The AFETR coverage capability was to be based on a configuration using land stations and two instrumentation ships. The proper positioning of the two ships should result in coverage of the near-earth class I tracking and telemetry requirements (except continuous telemetry coverage during the parking orbit) over reasonable-size launch windows. An estimate of the available launch windows is presented in the chart of Fig. 9. Because of AFETR commitments it is sometimes necessary to refine these windows.

Since major launch vehicle and spacecraft events take place automatically during the near-earth phase of the mission and have a strong impact on the success of the remaining phases of the mission, it is important that any failure in the TDS support to this phase during the countdown be carefully evaluated to determine a launch or hold condition.

The AFETR performs TDS supporting functions for *Surveyor* missions during the countdown, launch, and near-earth phase of the flight.

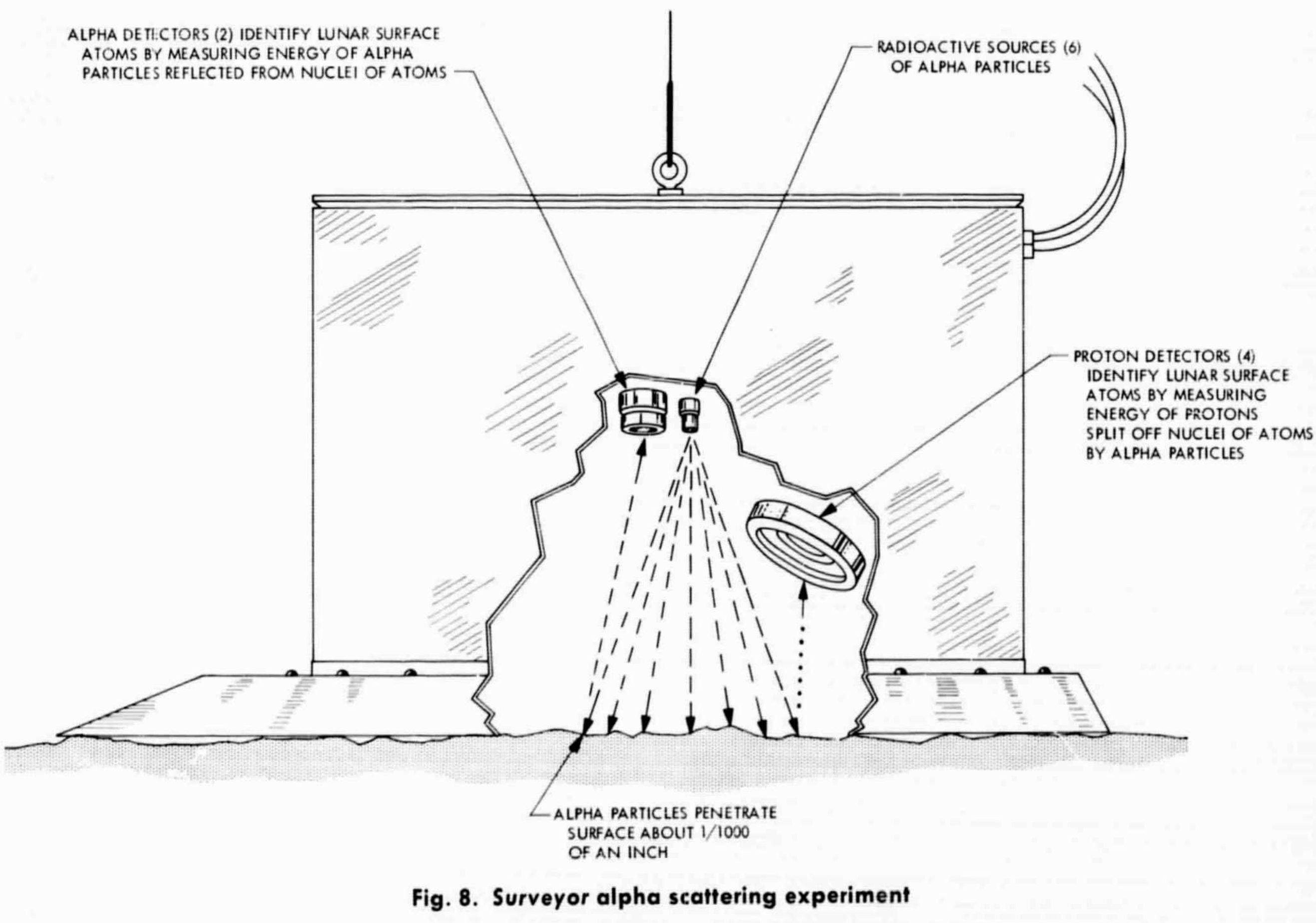
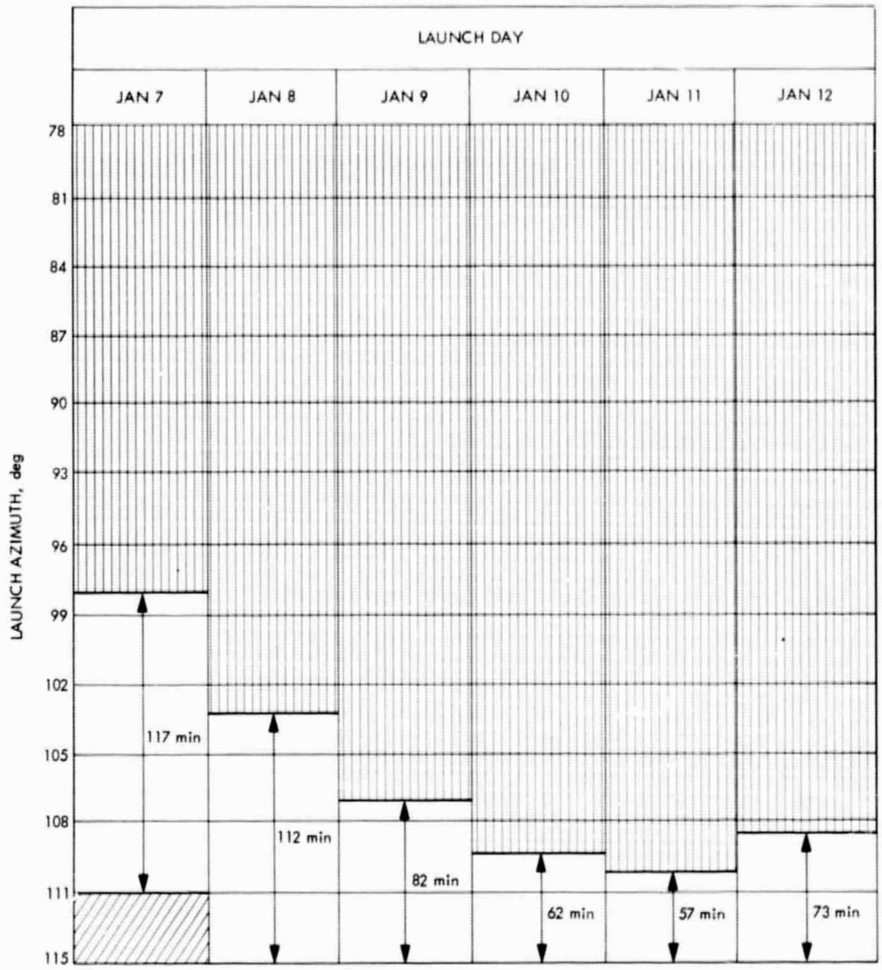
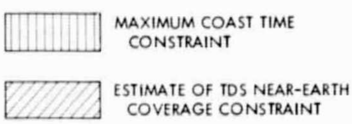


Fig. 8. Surveyor alpha scattering experiment



MAXIMUM WINDOWS

TIME	JAN 7		JAN 8		JAN 9		JAN 10		JAN 11		JAN 12	
	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE
GMT	05:43	08:12	06:36	08:28	07:29	08:51	08:24	09:26	09:19	10:16	10:11	11:24
EST	00:43	03:12	01:36	03:28	02:29	03:51	03:24	04:26	04:19	05:16	05:11	06:24
PST	21:43	00:12	22:36	00:28	23:29	00:51	00:24	01:26	01:19	02:16	02:11	03:24
AZ	97.7	115	103.1	115	106.9	115	109.3	115	110	115	108.4	115



ONE DAY EARLIER IF PST EXCEEDS GMT TIME
ROUNDED TO NEAREST MINUTE WITHIN CONSTRAINT
ALSO TDS CONSTRAINTS NOT INCLUDED

AZ – AZIMUTH, deg

Fig. 9. Surveyor launch window constraints for the January 1968 launch period (TDS constraints not included)

1. Near-earth tracking and telemetry requirements. It is the purpose of this subsection to provide information that will be useful in real-time decision making during the countdown in the event of loss of any of the planned TDS support for the near-earth phase, i.e., from launch to DSN initial acquisition. This information is contained in Tables 3 and 4.

Listed in Tables 3 and 4 are the class I tracking and telemetry coverage requirements, the basis for levying these requirements, their ratings of relative importance, and the required supporting stations. Three rating categories were selected. These are referred to as (1) critical, (2) highly desirable, and (3) desirable, in descending order of importance. Requirements were placed in one of these categories according to their role of supporting the following near-earth mission requirements:

(1) Near-real-time mission evaluation.

(2) Receive and record data for post-flight analysis.

It should be also noted that the AFETR Real-Time Computer System (RTCS) is critical for the near-real-time mission evaluation. Thus, at least one of the two RTCS 3600 computers must be operational at launch.

Figure 10 gives a comprehensive picture of the *Surveyor* near-earth class I tracking and data acquisition requirements for *Surveyor VII*. Figure 11 shows the projected AFETR uprange coverage for *Surveyor VII*; the event denoted parking orbit injection in this figure occurs at the end of the 76-s ullage period following main engine cutoff (MECO) 1. Figure 12 shows the earth tracks for the entire TDS on launch day.

Table 3. Near-earth class I tracking coverage requirements evaluation

Source	Class I tracking coverage requirements	Basis for requirements	Requirements rating	Required tracking stations[a]
Launch vehicle (C-band)	From launch to MECO 1	Provides a reasonable level of confidence for being able to track vehicle during parking orbit Required by Range Safety until velocity is acquired	Critical	Cape Kennedy Antigua
	Continuous 60 s from MECO 1 to MECO 1 + 136 s	Allows calculation of parking orbit so that: An early evaluation of the powered flight can be made Inflight acquisition information can be provided to downrange TDS stations beginning with the ships and Ascension DSN acquisition information can be generated based on the actual parking orbit and a theoretical second burn (constitutes first set of inflight predicts)	Critical	Antigua
	Any 60 s of continuous tracking from MECO 2 + 5 s to retro motor start	Input data for calculation of actual transfer orbit so that: An early evaluation of the transfer trajectory can be made using lunar mapping technique Inflight acquisition data can be provided to the DSN Acquisition information can be supplied to the MSFN station at Carnarvon, Australia	Critical	*Twin Falls* Pretoria
	Any 60 s of continuous tracking subsequent to power changeover switch	Establishes postretro trajectory of *Centaur* to determine any possible interference with the spacecraft star sensor	Highly desirable	Carnarvon Pretoria

[a]All of these stations are not necessarily required for each launch azimuth on each launch date. The mission director will be advised during the countdown which stations are required for the predicted launch azimuth.

Table 4. Near-earth class I telemetry coverage requirements evaluation

Source	Class I telemetry coverage requirements	Basis for requirements	Requirements rating	Required telemetry stations[a]
Launch vehicle (VHF) Spacecraft (S-band)	From launch to *Atlas*/*Centaur* separation	Provides *Atlas* performance data during its lifetime Establishes SECO[b] event time which is a good indicator of what can be expected for *Centaur* burn duration Receipt of spacecraft telemetry via *Centaur* link and spacecraft S-band link	Critical for receive and record Highly desirable to retransmit in real-time	Cape Kennedy
	From *Centaur* MES[c] 1 to MECO[d] 1	Provides *Centaur* performance data during its first burn Establishes MES 1 and MECO 1 event times Receipt of spacecraft telemetry via *Centaur* link and spacecraft S-band link	Critical for receive and record Highly desirable to retransmit in real-time	Cape Kennedy Antigua
	From MECO 1 to MECO 1 + 76 s	*Centaur* propellants are settled by thrusting two of the 50-lb vernier engines during this period Receipt of spacecraft telemetry via *Centaur* link and spacecraft S-band link	Critical for receive and record Highly desirable to retransmit in real-time	Antigua
	From MECO 1 + 76 s to MES 2 − 40 s	*Centaur* propellants are retained at tank outlets during this period by thrusting two of the 3-lb engines Receipt of spacecraft telemetry via *Centaur* link and spacecraft S-band link	Highly desirable to receive, record, and retransmit in real-time	Antigua Ascension
	From MES 2 − 40 s to MES 2	The following critical *Centaur* events take place: Further propellant settling applied by firing two of the 50-lb vernier engines Boost pumps are started Chilldown Receipt of spacecraft telemetry via *Centaur* link and spacecraft S-band link	Critical for receive and record Highly desirable to retransmit in real-time	*Twin Falls* Pretoria
	From MES 2 to MECO 2	Provides *Centaur* performance data during its second burn Establishes MES 2 and MECO 2 event times Receipt of spacecraft telemetry via *Centaur* link and spacecraft S-band link	Critical for receive and record Highly desirable to retransmit in real-time	*Twin Falls* Pretoria
Launch vehicle (VHF) Spacecraft (S-band)	From MECO 2 to *Centaur*/spacecraft separation	The following major spacecraft events occur: Release of spacecraft landing gear Unlock of spacecraft omniantennas Switch spacecraft transponder transmitter to high power *Centaur*/spacecraft separation	Critical for receive and record Highly desirable to retransmit spacecraft channel in real-time	Pretoria *Twin Falls*
Spacecraft (S-band)	From spacecraft high power on to DSN initial acquisition	Provides spacecraft status information	Critical for receive and record Highly desirable to retransmit in real-time	Pretoria Carnarvon

[a]All of these stations are not necessarily required for each launch azimuth on each launch date. The mission director will be advised during the countdown which stations are required for the predicted launch azimuth.
[b]Sustainer engine cutoff.
[c]Main engine start.
[d]Main engine cutoff.

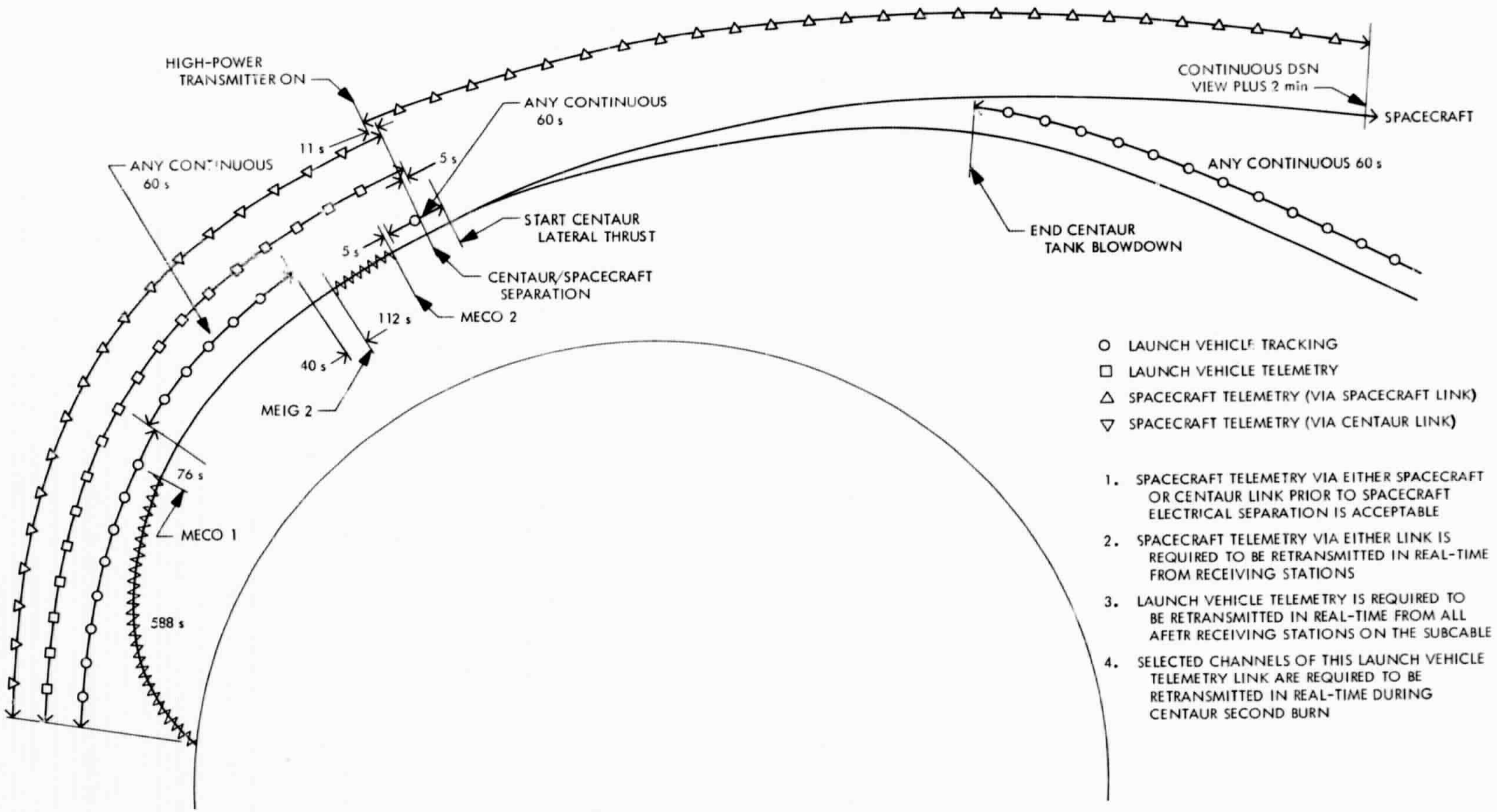


Fig. 10. Near-earth class I tracking and data acquisition requirements for *Surveyor VII*

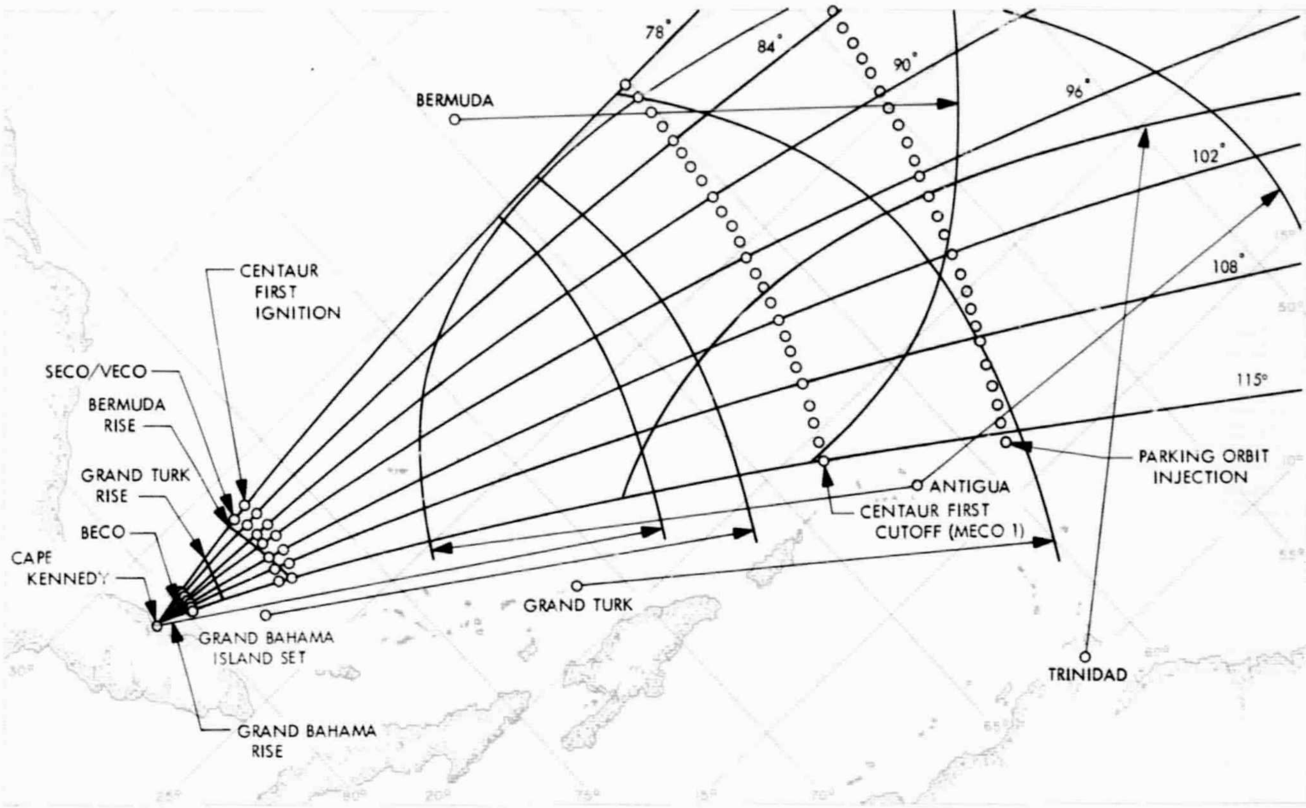


Fig. 11. Uprange coverage for *Surveyor VII*

Coverage of the transfer orbit tracking requirements can be met with a combination of the Pretoria and the *Twin Falls* radars. The Ascension radar could only provide tracking during the parking orbit because of the extreme downrange transfer orbit injection.

Figure 12 shows that the AFETR station at Pretoria, South Africa, could provide coverage of the requirement for post-retromaneuver tracking data for some azimuths on January 7 and 8. The MSFN Carnarvon radar could satisfy this requirement on all days for all azimuths.

Two AFETR range instrumentation ships were committed to support *Surveyor VII* in January. The ships and their planned locations for various launch days are presented in Table 5. It can be seen that the *Twin Falls* was to be stationed in the south Atlantic off the west coast of Africa and the *Sword Knot* in the Indian Ocean throughout the launch period. Both the *Twin Falls* and the *Sword Knot* were to be used to receive and record VHF launch vehicle and S-band spacecraft telemetry data. In addition, it was planned for the *Twin Falls* to track the C-band beacon aboard the *Centaur*.

*2. **Computed data.*** Using the overall tracking coverage data provided as indicated in Table 2, the AFETR real-time computer system was to provide the following:

(1) Parking orbit elements and injection conditions, standard orbital parameter message, and interrange vector based on actual parking orbit C-band radar tracking data.

(2) Parking orbit elements and injection conditions, standard orbital parameter message, and interrange vector based on *Centaur* guidance telemetry.

(3) Theoretical transfer orbit elements and injection conditions, standard orbital parameter message and interrange vector, based on parking orbit and nominal *Centaur* second-burn performance.

(4) Manned Space Flight Network look angles and DSN predicts, based on parking orbit and nominal *Centaur* second burn performance.

(5) Actual transfer orbit elements and injection conditions, standard orbital parameter message, interrange vector, lunar mapping message, and I-matrix,

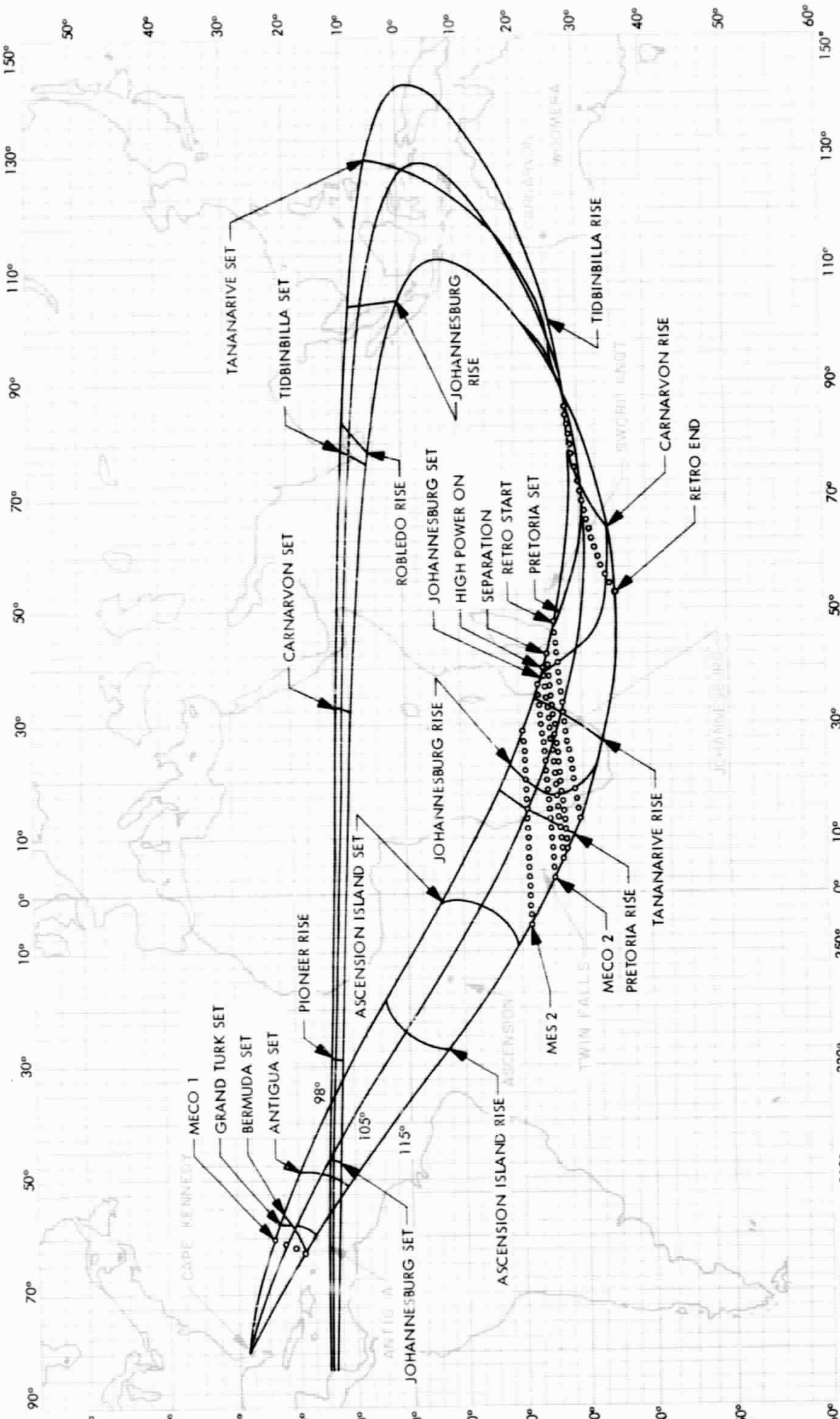


Fig. 12. Planned launch phase coverage for January 7, 1968

based on post transfer orbit injection C-band radar tracking data.

(6) Actual transfer orbit elements and injection conditions, standard orbital parameters message, interrange vector, lunar mapping message, and I-matrix, based on DSN tracking data.

(7) MSFN look angles and DSN predicts, based on actual transfer orbit.

(8) Actual post-retromotor orbit elements and injection conditions, standard orbital parameter message, interrange vector, lunar mapping message, and I-matrix, based on post-retromaneuver C-band radar tracking data.

(9) The AFETR and MSFN radar tracking data, reformatted to decimal format.

Table 5. Range instrumentation ship positions planned for *Surveyor VII*

Launch date	Ship	Position, deg	
		Latitude	Longitude
Jan 7	*Twin Falls*	23.7 S	4.0 E
	Sword Knot	26.0 S	53.0 E
Jan 8	*Twin Falls*	25.6 S	7.75 E
	Sword Knot	28.5 S	54.0 E
Jan 9	*Twin Falls*	28.0 S	11.0 E
	Sword Knot	30.5 S	54.0 E
Jan 10	*Twin Falls*	31.7 S	13.2 E
	Sword Knot	32.0 S	54.0 E
Jan 11	*Twin Falls*	33.0 S	17.0 E
	Sword Knot	32.0 S	55.0 E
Jan 12	*Twin Falls*	33.0 S	17.0 E
	Sword Knot	31.5 S	55.0 E

3. Real-time retransmission of telemetry data. Real-time retransmission of spacecraft telemetry data to building AO and DSS 71 was required, as follows: (1) via the *Centaur* 225.7-MHz link, from $T - 10$ min to *Centaur/Surveyor* electrical disconnect, and (2) via the spacecraft 2295-MHz link, from spacecraft high-power transmitter on to continuous DSN view plus 2 min.

When more than one station viewed the High-Power-On event, one station was to be configured to retransmit that spacecraft event in real-time. For the other viewing station, it was a class I requirement to retransmit launch vehicle performance data during the interval from MES 2 -40 s through MECO 2.

C. Manned Space Flight Network

The MSFN, managed by GSFC, supported the *Surveyor VII* Mission by performing the following functions:

(1) Tracking of the *Centaur* beacon (C-band).

(2) Receiving and recording *Centaur*-link telemetry.

(3) Receiving, recording and retransmitting S-band telemetry to DSS 42 in real-time.

(4) Providing real-time confirmation of certain *mark* events.

(5) Providing computing support through the use of the GSFC data operations branch.

(6) Providing NASCOM support to all NASA elements for simulations and launch, and extending this communications support as necessary to interface with the combined worldwide network.

The MSFN tracking and telemetry facilities and equipment used in support of *Surveyor VII* are listed in Table 6. The MSFN also supported the operational readiness test (ORT) prior to launch.

Table 6. Manned Space Flight Network configuration

Location	Acquisition	VHF telemetry	S-band telemetry	C-band radar	SCAMA[a]	Radar high-speed data	Real-time readouts
Bermuda	X	X		X	X	X	X
Tananarive	X	X		X	X		X
Carnarvon	X	X	X	X	X		X
GSFC					X	X	

[a]Signaling, conferencing, and monitoring arrangement.

1. Acquisition aids. The MSFN stations were equipped with acquisition aids to track the vehicle and provide RF inputs to the telemetry receivers from acquisition of signal (AOS) to loss of signal (LOS). Performance recorders are used to record automatic gain control and angle errors for post-mission analysis. The acquisition aid systems performed their required functions during the *Surveyor VII* Mission.

2. Telemetry data. The MSFN stations are also equipped to decommutate, receive, and record telemetry. The telemetry requirements placed on the MSFN were:

(1) Bermuda, Tananarive, and Carnarvon were to receive and record the *Centaur* 225.7-MHz link from AOS to LOS.

(2) Bermuda was to receive and record the *Atlas* 229.9-MHz link from AOS to LOS.

(3) *Centaur mark* event readouts were required from Bermuda, Tananarive, and Carnarvon in real-time or as close to real-time as possible, after the vehicle was in view of the station.

(4) Bermuda was to display range safety parameters on the *Atlas* and *Centaur* links.

(5) Carnarvon was to receive, record, and retransmit S-band telemetry to DSS 42 in real-time.

(6) All stations were to provide recordings and post-launch instrumentation message (PLIM) data sheets.

3. Tracking. The C-band radars at Bermuda, Tananarive, and Carnarvon were required to beacon track the *Centaur* vehicle. All stations were to provide real-time data, magnetic tape recordings of high-speed data and verbal confirmation of the time of AOS and LOS to the MSFN network controller.

Bermuda station requirements were as follows:

(1) Beacon tracking and magnetic tape recordings of the *Centaur* from AOS to LOS; FPQ-6 radar to actively beacon track; FPS-16 to passively angle track.

(2) Real-time transmission of high-speed data and low-speed data to GSFC and RTCS at AFETR.

(3) Voice circuit for handover between Bermuda and AFETR.

(4) Verbal confirmation in real-time of the time of AOS and LOS to MSFN network controller.

(5) Magnetic tape recordings, strip chart recordings, and PLIM data sheets.

Tananarive and Carnarvon station requirements were as follows:

(1) Beacon tracking and magnetic tape recording of the *Centaur* from AOS to LOS. Tananarive to support on an engineering basis.

(2) Real-time transmission of low-speed data from Carnarvon to GSFC for reformatting and retransmission to RTCS at AFETR. Tananarive was to transmit low-speed data in the standard 38-character radar data format to RTCS at AFETR.

(3) Voice circuit for radar handover between Tananarive and AFETR and between Carnarvon and AFETR.

(4) Verbal confirmation in real-time of the time of AOS and LOS to the MSFN network controller.

(5) Magnetic tape recordings, strip chart recordings and PLIM data sheets.

4. Telemetry (VHF). The MSFN stations at Bermuda, Tananarive and Carnarvon, as well as portions of the NASCOM network and the GSFC/AFETR interface at Cape Kennedy, were to support this mission.

Coverage of the *Centaur* 225.7-MHz link for receive and record was required from Bermuda, Tananarive, and Carnarvon. In addition, Bermuda was to receive and record the *Atlas* 229.9-MHz link.

Mark event readouts were required from all stations, in real-time or as close to real-time as possible, when the vehicle was in view of a station.

All stations were to provide verbal confirmation in real-time of the GMT of AOS, *mark* events and LOS to the MSFN network controller. Real-time transmission of certain telemetry data was required from Tananarive.

a. Bermuda requirements. Bermuda was requested to perform the following functions:

(1) Receive and record the *Centaur* 225.7-MHz link from AOS to LOS.

(2) Receive and record the *Atlas* 229.9-MHz link for range safety purposes.

(3) Display range safety parameters on the *Atlas* and *Centaur* links.

(4) Provide real-time readout of *mark* events.

(5) Teletype confirmation of *mark* events.

(6) Furnish magnetic tape recordings, strip chart recordings, and PLIM data sheets.

b. Tananarive requirements. Tananarive was required to perform the following functions:

(1) Receive and record the *Centaur* 225.7-MHz link from AOS to LOS.

(2) Provide real-time readout of *mark* events.

(3) Teletype confirmation of *mark* events.

(4) Transmit in real time, via voice/data circuits, specified telemetry data to hangar AE at AFETR.

(5) Furnish magnetic tape recordings, strip chart recordings, and PLIM data sheets.

c. Carnarvon requirements. Carnarvon was required to perform the following functions:

(1) Receive and record the *Centaur* 225.7-MHz link from AOS to LOS.

(2) Provide real-time readout of *mark* events.

(3) Furnish teletype confirmation of *mark* events.

(4) Furnish magnetic tape recordings, strip chart recordings, and PLIM data sheets.

5. Telemetry (S-band). There was a requirement for Carnarvon reception of S-band spacecraft telemetry data and retransmission to DSS 42 at Tidbinbilla.

6. Computer requirements. The requirements levied on the Manned Space Flight Network, with respect to computer support, were to:

(1) Provide pointing data printouts to be used for mission planning and for committing MSFN station coverage.

(2) Generate and transmit nominal pointing data to participating MSFN stations.

(3) Receive launch trajectory data from Bermuda and AFETR, via the launch trajectory data system.

(4) Generate radar simulation tapes for Tananarive and Carnarvon.

(5) Update and refine the orbit of the *Centaur* based on low-speed TTY data received from participating C-band radars, and pass these data to the MSFN network controller.

(6) Use the launch trajectory data to drive displays at the GSFC operations control center.

(7) Generate and transmit real-time acquisition messages to participating MSFN stations.

(8) Reformat Carnarvon radar data to the standard 38-character radar data for transmission to RTCS at AFETR.

(9) Reformat on magnetic tape the high-speed radar data received from AFETR in the tape format specified (XYZ and $\dot{x}\dot{y}\dot{z}$) and reformat on magnetic tape the low-speed teletype data received from AFETR and MSFN in the standard time, azimuth, elevation, and range format for shipment to the *Centaur* office at Lewis Research Center.

(10) Reformat on magnetic tape the Bermuda high-speed raw data, including a list of the contents and formats for shipment to the RCA data processing requirements group at Patrick AFB.

D. Deep Space Network

The DSN was required to support the *Surveyor VII* Mission with the Deep Space Instrumentation Facility, the ground communication system, and the DSN facilities in the Space Flight Operations Facility.

The DSN support included S-band tracking and two- and three-way doppler coverage. The DSN was responsible for obtaining continuous spacecraft telemetry coverage from the first acquisition by Tidbinbilla, Australia (DSS 42) to the end of the mission. The Deep Space Stations noted herein were required for this coverage. The full Goldstone duplicate standard S-band system in conjunction with the *Surveyor* telemetry system was used at these stations.

The quality and type of tracking data required is defined in Tables 7 and 8. These tables specify the tracking coverage required to meet the orbit determination accuracy requirements. Before presenting the tracking coverage requirements, however, it would be proper to delineate the ground rules upon which the tracking coverage was based.

The most basic and paramount ground rule was that the primary objective of this effort was to maximize the probability of mission success. Since the class I orbit determination accuracy requirement had to be satisfied to ensure that the primary mission objectives were met, it was necessary that these class I requirements be honored at all times. In addition, it was necessary that

Table 7. Deep Space Network tracking data accuracy requirements

Data accuracy	Correlation width T_l, min	Two-way doppler (1-σ), Hz	Angles (1-σ), Hz	Three-way doppler (1-σ), Hz	Time sync, s	Absolute frequency stability over 1-min intervals
		Effective noise at 1 sample/min				
A, guaranteed	$T_l < 1$	0.01	0.05	0.05	0.005	5.0×10^{-11}
	$1 \leq T_l < 10$	0.01	0.05	0.05		
	$T_l \geq 10$	0.1	0.2	20.0		
B, desired, not guaranteed	$T_l < 1$	0.005	0.01	0.005	0.001	3.0×10^{-12}
	$1 \leq T_l < 10$	0.005	0.01	0.005		
	$T_l \geq 10$	0.005	0.06	0.005		
C, ultimate *Surveyor* block I	$T_l < 1$	0.001	0.005	0.001	0.00001	3.0×10^{-13}
	$1 \leq T_l < 10$	0.001	0.005	0.001		
	$T_l \geq 10$	0.001	0.014	0.001		

Table 8. Deep Space Network tracking data requirements

Coverage and sampling rate	Data required
Track spacecraft from separation to first midcourse maneuver at 1-sample/min rate (from initial DSS acquisition to $T + 1$ h, sample rate is 1 sample/10 s)	Doppler (two- and three-way) and antenna pointing angles
Track spacecraft from first midcourse maneuver to touchdown at 1 sample/min	Doppler (two- and three-way)
Track spacecraft from touchdown to end of mission at 1-sample/min rate during 1 h following 10-deg elevation rise, during 1 h centered around maximum elevation, and during 1 h prior to 10-deg elevation set for DSSs 11, 42, and 61	Doppler (two- and three-way) and antenna pointing angles
Track spacecraft during midcourse maneuver and terminal maneuver executions at the 1-sample/s rate, and transient data at the 1-sample/10 s rate	Doppler (two- and three-way or one-way)

some class II orbit determination accuracy requirements be met to ensure achieving a mission success. However, the class III accuracy requirements would not have to be satisfied to ensure achieving a mission success.

Therefore, the greatest effort was directed toward the goal of determining the optimum scheme for meeting the class I orbit determination accuracy requirements.

Specification of the class I tracking coverage requirements in support of the class I orbit determination accuracy was based upon the assumption that each DSN station supplying necessary data would, in fact, supply data of good quality. To ensure that there would be a supply of good-quality data, it was desirable to assign additional DSN stations to a tracking pattern, arranged so as to provide redundancy.

The prime DSN coverage was to be provided by DSSs 11, 42, 51, and 61. Figure 13 presents the coverage of these stations through the first 20 h after launch. Additional DSN support was provided by DSSs 14 and 71; DSS 14 was to provide DSS 11 backup support with its 210-ft antenna during the midcourse maneuver and terminal descent phases. Cape Kennedy (DSS 71) was to provide prelaunch checkout and launch phase support of the spacecraft; DSS 71 was also the key interface in relaying spacecraft telemetry data from the AFETR to the SFOF in Pasadena.

The initial DSN acquisition station was DSS 42. This was the only station with view periods which permitted commanding the spacecraft transmitter to switch from high to low power before the thermal limit was reached.

1. Deep Space Instrumentation Facility. The DSIF was required to provide all support arranged for *Surveyor VII*. A bar chart of Deep Space Station view periods for the various January 1968 launch opportunities is presented in Fig. 14.

a. Initial acquisition station. The following minimum capabilities were required from the initial acquisition station:

(1) Acquisition and tracking of the *Surveyor* spacecraft.

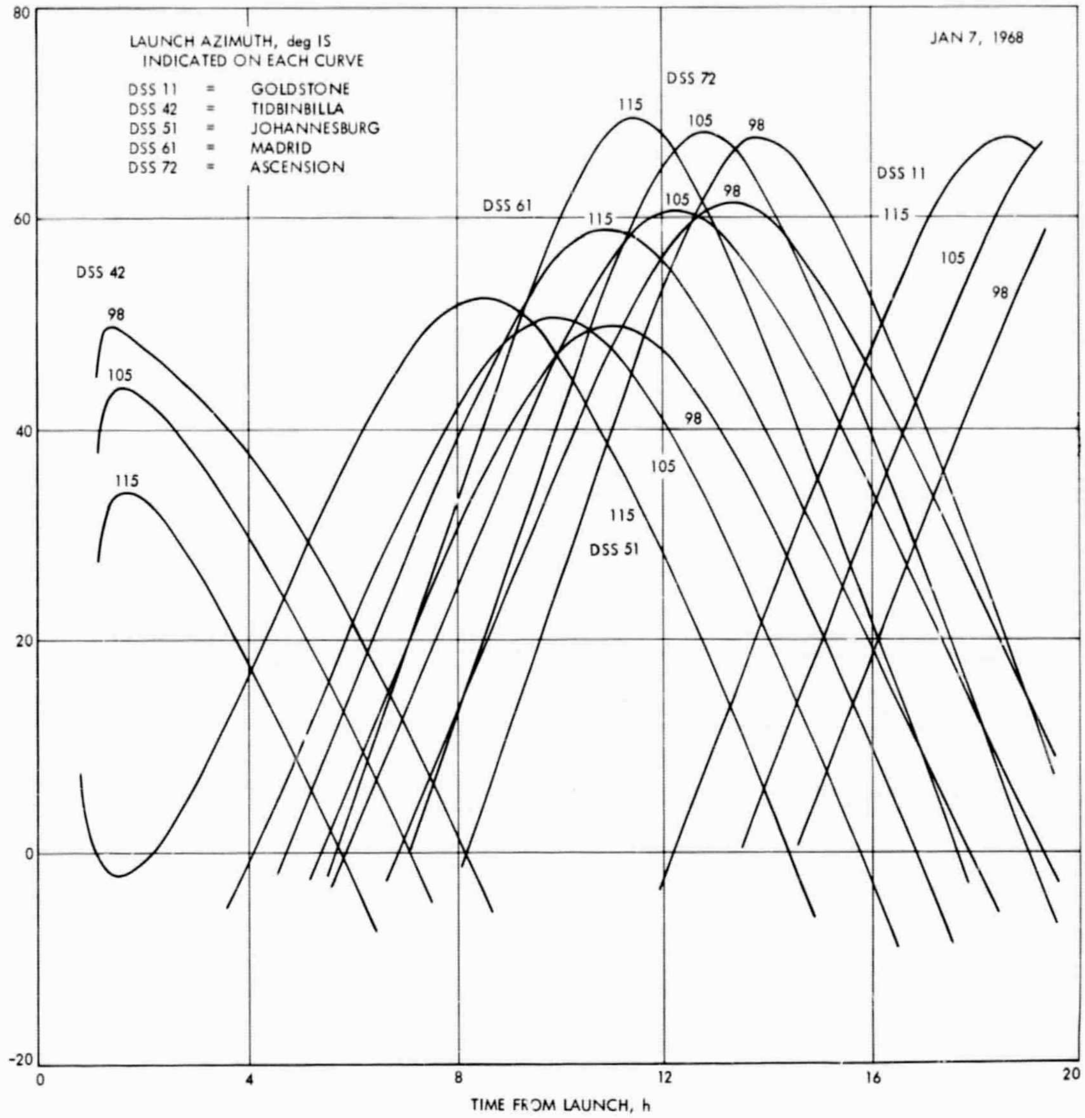


Fig. 13. Station elevation angle vs time from launch (0–20 h)

(2) Generation and transmission of tracking data to the communications terminal equipment at the site.

(3) Acquisition, recording, decommutation, display, and processing of *Surveyor* spacecraft telemetry data.

(4) Transmission of processed telemetry data, both high speed and TTY, to the appropriate communications terminal equipment at the site.

(5) Generation and transmission of *Surveyor* spacecraft commands.

b. Acquisition criteria. The criteria for DSIF acquisition of a spacecraft are as follows:

(1) The DSIF will employ the acquisition aid antenna and either the parametric amplifier or the second maser to the receiver. This configuration will be used to determine the tracking margin.

(2) The tracking phase lock loop phase error due to the doppler rate will not exceed 30 deg.

(3) A signal level of −140 dBmW deg or higher must be available.

(4) For an 85-ft antenna, the angular rate of the DSIF-spacecraft vector must not exceed 0.25 deg/s during acquisition.

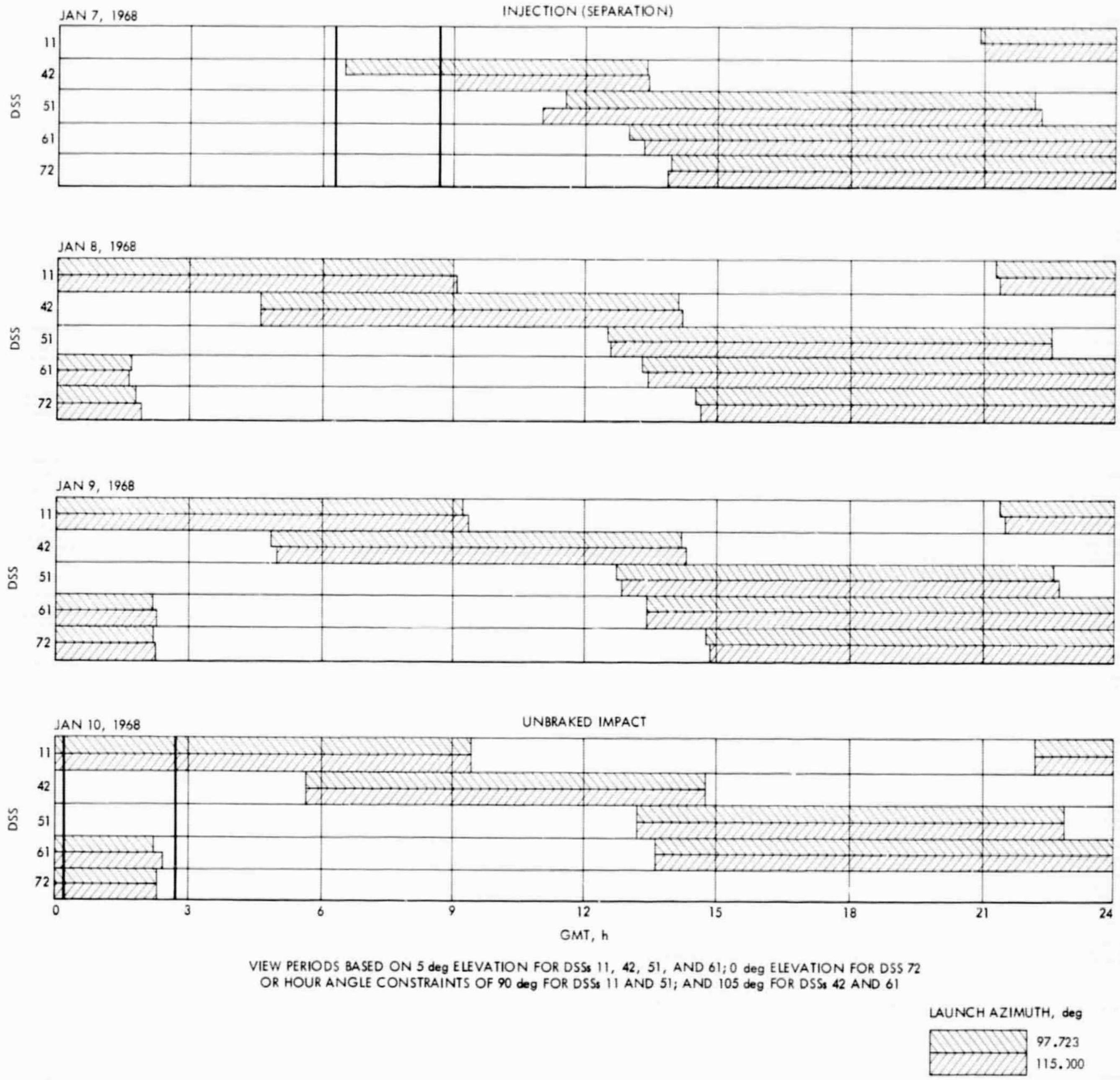


Fig. 14. Bar charts of station view periods

(5) The antenna angular rates during auto track must not exceed 0.85 deg/s for 85-ft antenna.

(6) Auto track on subcarrier modulation cannot be obtained until the elevation angle of the spacecraft is more than 10 deg above the local horizon.

(7) From the 10-deg elevation point, 20 min will be allowed for the DSIF to acquire the spacecraft and obtain auto track on subcarrier modulation.

(8) Acquisition will be considered complete when the uplink and the two-way downlink are acquired.

c. Additional requirements. With a high degree of probability, it is required that at the start of the applicable Deep Space Station's views, the following minimum capabilities exist:

(1) Acquisition and tracking of the *Surveyor* spacecraft.

(2) Generation and transmission of tracking data to the communications terminal equipment at the site.

(3) Acquisition, recording, decommutation, display, and processing of *Surveyor* spacecraft telemetry data.

(4) Transmission of processed telemetry data, both high speed and TTY, to the appropriate communications terminal equipment at the site.

(5) Generation and transmission of *Surveyor* spacecraft commands.

At DSS 11 only, in addition to the aforementioned requirements, it is required that (with a high degree of probability at the start of the DSS 11 view) the following capability exist: acquisition, recording, and processing of *Surveyor* spacecraft video data.

With a high degree of probability, it is required that at the start of the Deep Space Station respective views, the following minimum communication capabilities exist for each committed Deep Space Station:

(1) One voice line.

(2) Two duplex teletype lines.

At DSS 11 only, in addition to the aforementioned requirements, with a high degree of probability at the start of DSS 11 view, the following communication capability will be operational: one high-speed data line (1100 bits/s or 96 kHz).

2. *Ground Communications Facility/NASCOM.* Communications support was to be provided as in previous *Surveyor* missions. A plan was developed for maintaining operation of critical TTY circuits to and from the prime Deep Space Stations in the event of a communications processor failure. This plan was documented in the communications support plan, and hardwire TTY circuits were available if required.

Other GCF/NASCOM requirements are listed in Vol. IV of this report.

3. *Deep Space Network/SFOF.* The SFOF was designed to provide a reliable, flexible, centralized, and relatively mission-independent capability to conduct and control simultaneous lunar or planetary missions. The SFOF, in meeting its requirements to the *Surveyor* Project, dedicated numerous of these mission-independent capabilities in support of the *Surveyor VII* Mission. These capabilities included such operating functions as communications, displays, and data processing.

The following minimum capabilities were required in the SFOF:

(1) One operational TPS 7288-7044 computer string in the mode III configuration.

(2) Two operational 7094 computers in the mode IV configuration.

(3) Diesel generators as the power source for all SFOF computers committed to *Surveyor*.

(4) The operational voice communications subsystem committed to *Surveyor* less its intercom capability.

(5) Closed circuit TV displays of teletype data and line status.

(6) Transmission of incoming telemetry data, both high speed and teletype to the appropriate processing and display devices.

IV. *Surveyor VII* TDS Flight Preparation

The TDS was responsible for tracking and data preparations for the *Surveyor VII* flight. Flight preparation was accomplished by the unique TDS configuration and testing discussed in this section.

A. Configuration

The configuration of individual agencies that comprised the TDS in preparation for the *Surveyor VII* flight described herein.

1. *Air Force Eastern Test Range.* The AFETR configured its facilities in such a manner as to give maximum coverage for the near-earth phase of the *Surveyor VII* Mission. The various facilities and their preparations to meet the requirements placed on the AFETR are discussed here. The AFETR stations and facilities prelaunch configuration committed to support *Surveyor VII* are seen in Table 9. Figure 15 shows the view periods for all stations during the first hour of the near-earth phase.

a. Tracking. The AFETR was to provide adequate C-band coverage of the powered flight and parking orbit requirements with their up-range stations. Table 10 gives the AFETR station facilities and their various capabilities.

The C-band radar coverage that was planned, along with the range instrumentation ship, and land-based stations used in this connection, is shown in Fig. 16.

b. Telemetry (VHF). The planned telemetry configuration and coverage for *Surveyor VII* is shown in Fig. 17.

Table 9. Air Force Eastern Test Range prelaunch configuration, *Surveyor VII*

Station	Radar	VHF telemetry	S-band telemetry
Merritt Island	X	X	X
Cape Kennedy	X		
Patrick AFB	X		
Grand Bahama	X	X	X
Grand Turk	X		
Antigua	X	X	X
Twin Falls	X	X	X
Ascension	X	X	X
Pretoria	X	X	X
Sword Knot		X	X

c. Telemetry (S-band). Figure 18 indicates the planned S-band telemetry coverage by the various AFETR RIS and land stations for *Surveyor VII.*

d. Computed data. In addition to relaying the data to JPL, the RTCS was to use the data to compute orbital elements and injection conditions (parking orbit, transfer orbit and post-retro) which would be transmitted to JPL in the following formats: (1) standard JPL orbital message, (2) interrange vector, and (3) standard orbital parameter message.

All DSN and MSFN acquisition information, based on the parking orbit plus theoretical second burn and actual pre-retro orbital computations, were to be prepared and forwarded by the RTCS.

A "mapping to lunar encounter" message was to be prepared for both the pre- and post-retro orbits. Following the single-station solutions, the RTCS was to compute

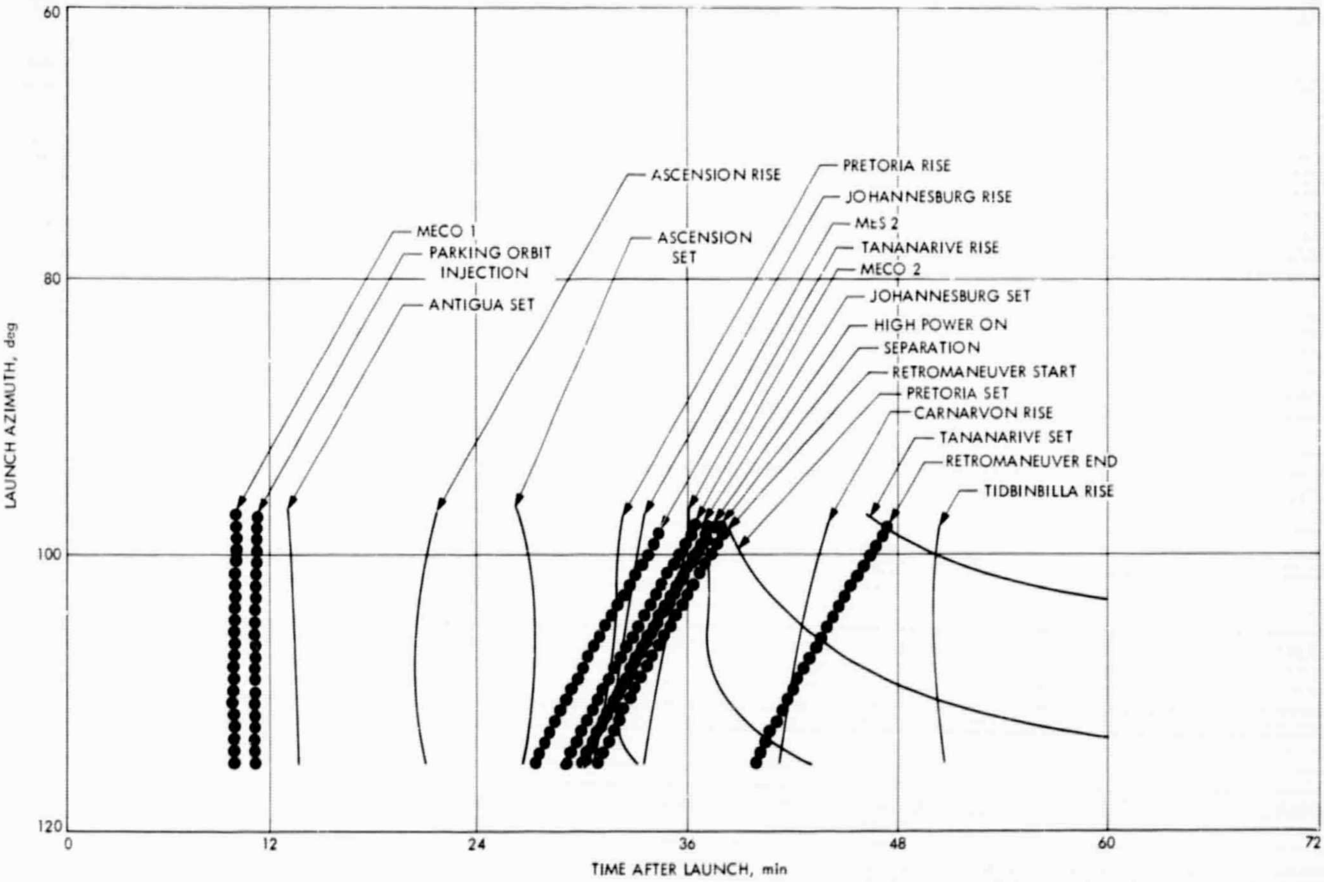


Fig. 15. View period graph for first hour for January 7, 1968

Table 10. Air Force Eastern Test Range station facilities

Station	Tracking capability (radar type)	Telemetry capability
AFETR stations		
Cape Kennedy Area	C-band	VHF; S-band
Patrick AFB	0.18 (FPQ-6)	KSC
Cape Kennedy	1.16 (FPS-16)	
KSC	19.18 (TPQ-18)	
Grand Bahama	C-band 3.16 (FPS-16) 3.18 (TPQ-18)	VHF; S-band
Grand Turk	C-band 7.18 (TPQ-18	VHF
Antigua	C-band 91.18 (FPQ-6)	VHF; S-band
Ascension	C-band 12.16 (FPS-16) 12.18 (TPQ-18)	VHF; S-band
Pretoria	C-band 13.16 (MPS-25)	VHF; S-band[a]
AFETR ships		
Sword Knot (10-knot cruising speed)		VHF; S-band
Twin Falls (15-knot cruising speed)	C-band (FPS-16)	VHF; S-band

[a]Three-ft antenna only.

and transmit to JPL pre- and post-retro recursive accumulative orbits. An I-matrix and a lunar mapping message based on each solution would be included.

2. *Manned Space Flight Network.* The MSFN, managed by GSFC, was configured to support the *Surveyor VII* Mission by providing tracking, VHF telemetry, and computer support.

Table 11 shows the GSFC/MSFN station and equipment configuration used for supporting *Surveyor VII.*

All MSFN flight preparation for *Surveyor VII* was similar in scope and requirements to that of *Surveyor VI.*

3. *Deep Space Network.* The DSN supports *Surveyor* missions with the integrated facilities of the DSIF, the Ground Communications Facility and the SFOF.

The DSN provides a command and telemetry link with the spacecraft upon initial acquisition of spacecraft signals by a DSIF station, enabling the DSIF station to control the spacecraft and furnish range rate data, angular tracking data, and real-time telemetry data to the SFOF. Continuous tracking and control is then provided throughout the remainder of the mission by the prime DSIF stations designated to support each *Surveyor* mission.

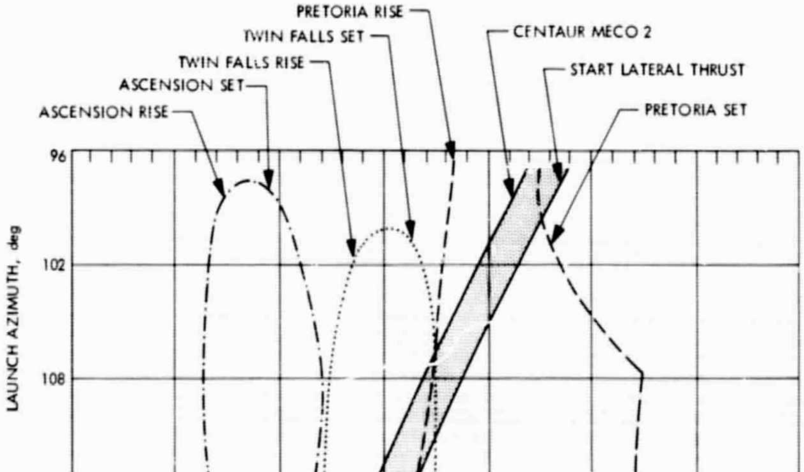


Fig. 16. C-band radar coverage

After the SFOF has accumulated sufficient tracking data, an orbit is determined that predicts the future path of the spacecraft. These data allow the computation of a midcourse maneuver to compensate for injection errors. The DSIF under control of the Mission Operations System, commands the midcourse maneuver after engineering telemetry and tracking data are gathered and transmitted via the GCF to the SFOF. The midcourse

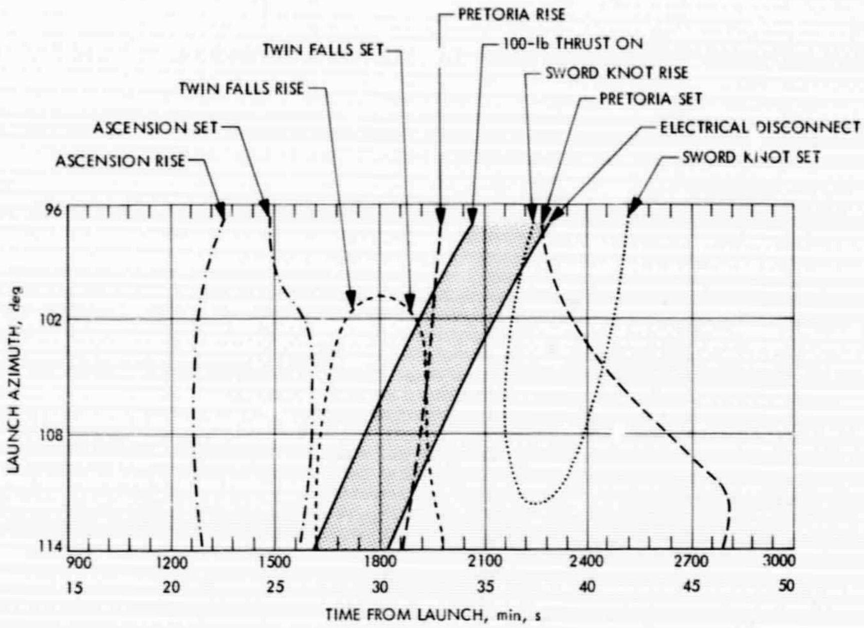


Fig. 17. Telemetry coverage and configuration (225.7 MHz)

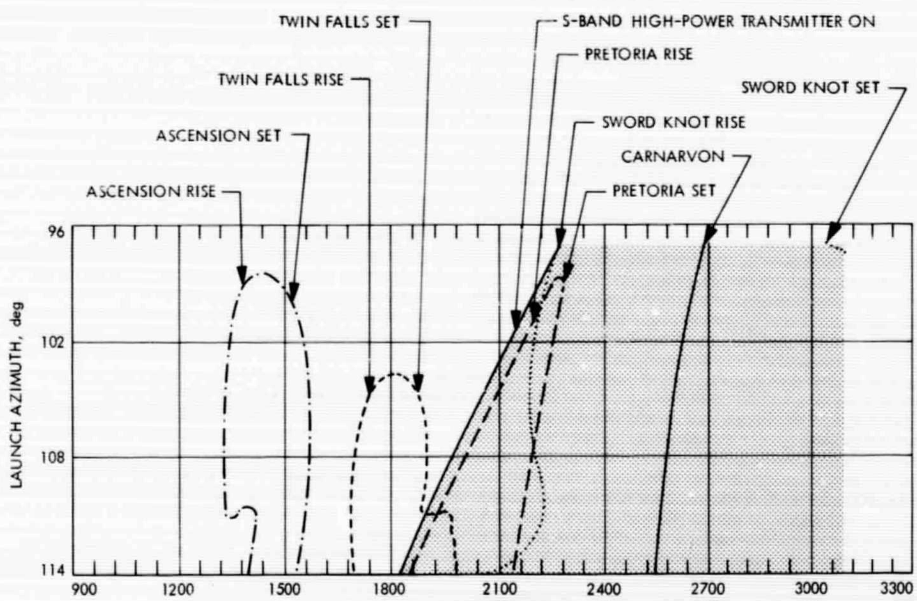


Fig. 18. S-band telemetry coverage

Table 11. *Surveyor VII* MSFN configuration

Location	Acquisition	Telemetry	C-band radar	Unified S-band	SCAMA[a]	Teletype	Radar high-speed data	Radar low-speed data	Real-time readouts	Real-time trans-missions
Bermuda	X	X	X		X	X	X	X		
Tananarive	X	X	X		X	X		X	X	
Carnarvon	X	X	X	X	X	X		X	X	X[b]
GSFC					X	X	X	X	X	
GSFC/AFETR interface					X	X	X	X		

[a]Signaling, conferencing, and monitoring arrangement.
[b]Telemetry data.

maneuver is evaluated at the SFOF, and appropriate commands for the terminal maneuvers are computed. After touchdown, Deep Space Stations receive video, and engineering and scientific telemetry data, as well as command the spacecraft during the lunar operations.

B. Deep Space Instrumentation Facility

The following Deep Space Stations were committed as prime stations for support of the *Surveyor VII* Mission:

DSS	Name and Location
11	Pioneer, Goldstone Deep Space Communications Complex, Barstow, Calif.
42	Tidbinbilla, Australia, near Canberra
61	Robledo, Spain, near Madrid

In addition to the basic support provided by prime stations, the following support was provided for the *Surveyor VII* Mission:

(1) DSS 71, Cape Kennedy, provided facilities for spacecraft/DSIF compatibility testing, and also received and recorded telemetry data after liftoff. In addition, DSS 71 used its command and data console (CDC) and telemetry and command processor computer to process AFETR range telemetry data for transmission to JPL.

(2) DSS 14 Mars, Goldstone Deep Space Communications Complex, Barstow, Calif., provided backup tracking and command support during midcourse and terminal maneuvers, using its 210-ft diam antenna. At touchdown, the baseband telemetry output of the DSS 14 prime receiver was transmitted to the SFOF.

(3) DSS 51, Johannesburg, South Africa, provided initial two-way acquisition and spacecraft commanding and tracking support during the transit phase.

For the January 7 launch date, DSS 42 was designated the initial two-way acquisition station as it met all the acquisition criteria of both the DSIF and the *Surveyor* Project.

Figure 19 gives a view period graph for the first 20 h for January 7, 1968.

C. Deep Space Network

The NASCOM/GCF intracommunications systems were considered to be in excellent condition to support the *Surveyor VII* Mission with no major problem areas.

1. Ground communications facility. Changes in the GCF from *Surveyor VI* Mission were all minor in scope (Fig. 20). They were as follows:

(1) One voice line (GP58726) was installed to interconnect AFETR and SFOF rooms 105 and 323. This line did not appear on the operational voice communications subsystem console nor in any other area under communications jurisdiction. One additional voice landline backup circuit (GP7213) was installed between JPL and Goldstone. This provided a total of five voice/data backup if microwave were to fail.

(2) Teletype circuits remained the same as those for *Surveyor VI* (Fig. 21).

(3) Changes in the high-speed data configuration from that for *Surveyor VI* were minor. The configuration included:

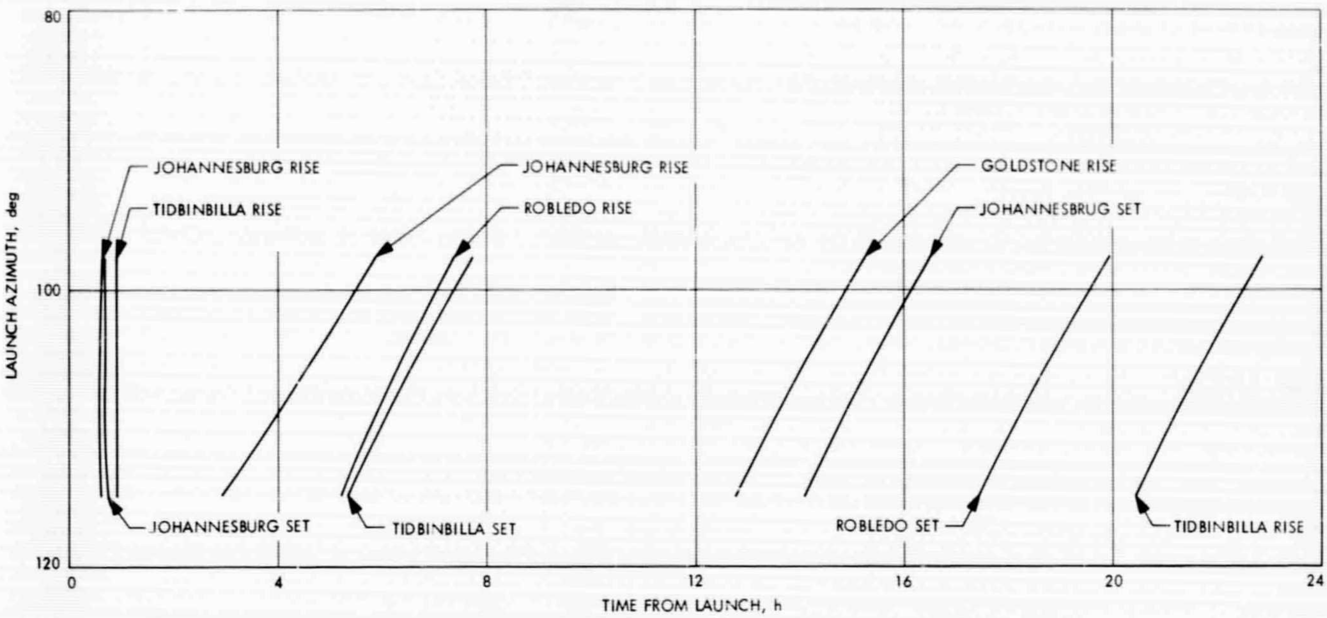


Fig. 19. View period graph for first 20 h for January 7, 1968

(a) A 96-kHz line again carried DSS 14 high-speed data direct to SFOF during midcourse and touchdown (Fig. 22).

(b) Carnarvon data via DSS 42 CDC and high-speed data line were available as in earlier missions (Fig. 23).

(c) Downrange data from AFETR 12 were relayed via DSS 72 high-speed data line from $T - 5$ h, 30 min to $T + 1$ h.

(4) No major changes have been made to this JPL/Goldstone microwave system. The antennas destroyed by the brush fire at Sierra Peak in October were replaced.

Special maintenance coverage for this system was requested by the project as follows:

Phase	Requested coverage
Launch	None
First midcourse	$T + 17$ to $T + 25$ h (8 h)
Second midcourse	$T + 39$ to $T + 47$ h (8 h)
Touchdown/terminal	$T + 59$ to $T + 69$ h (10 h)

(5) The communications processor, from a communications standpoint, was well capable of supporting the *Surveyor VII* Mission.

A plan was devised and equipment was implemented and tested end-to-end to pass real-time data via hardware teletype circuits in case of major communications processor failure at JPL, GSFC, London, or Canberra. This plan was called the emergency bypass facility and functioned as follows: In the event of communications processor failure during critical phases of the *Surveyor VII* Mission, low-speed emergency TTY circuits around the communications processors were to be utilized. The required hardware TTY circuits around the processors were to be made at the time each station's TTY circuits were activated. This emergency configuration is shown in Fig. 24. Included were the following features:

(1) Inbound low-speed TTY tracking data entered (after appropriate speed change at GSFC or SFOF) into the TSS bus on the DSS's A line. The DSN monitor area connected the reperforator on the appropriate line and converted the tracking data to paper tape. The paper tape was fed into IBM 047s (in the monitor area) and converted to cards. The cards were delivered to flight path analysis and command 1 and entered into the data processing system by means of card readers using established procedures.

(2) Teletype telemetry data were entered (after appropriate speed change at GSFC or SFOF) into the teletype switching system bus and could be punched up on appropriate SPAC teletype machines and processed in the normal manner.

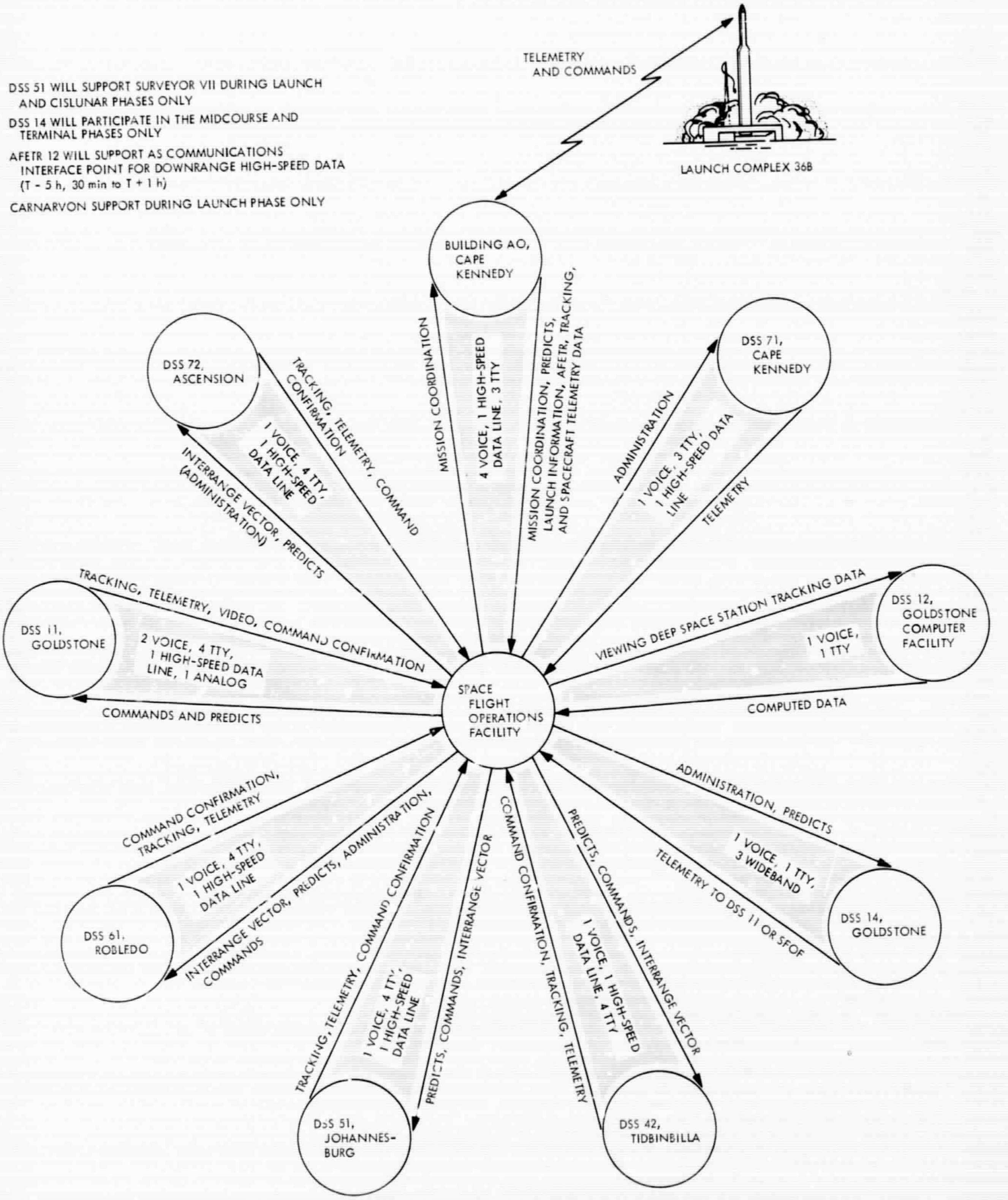


Fig. 20. Deep Space Network/GCF configuration diagram, Surveyor VII

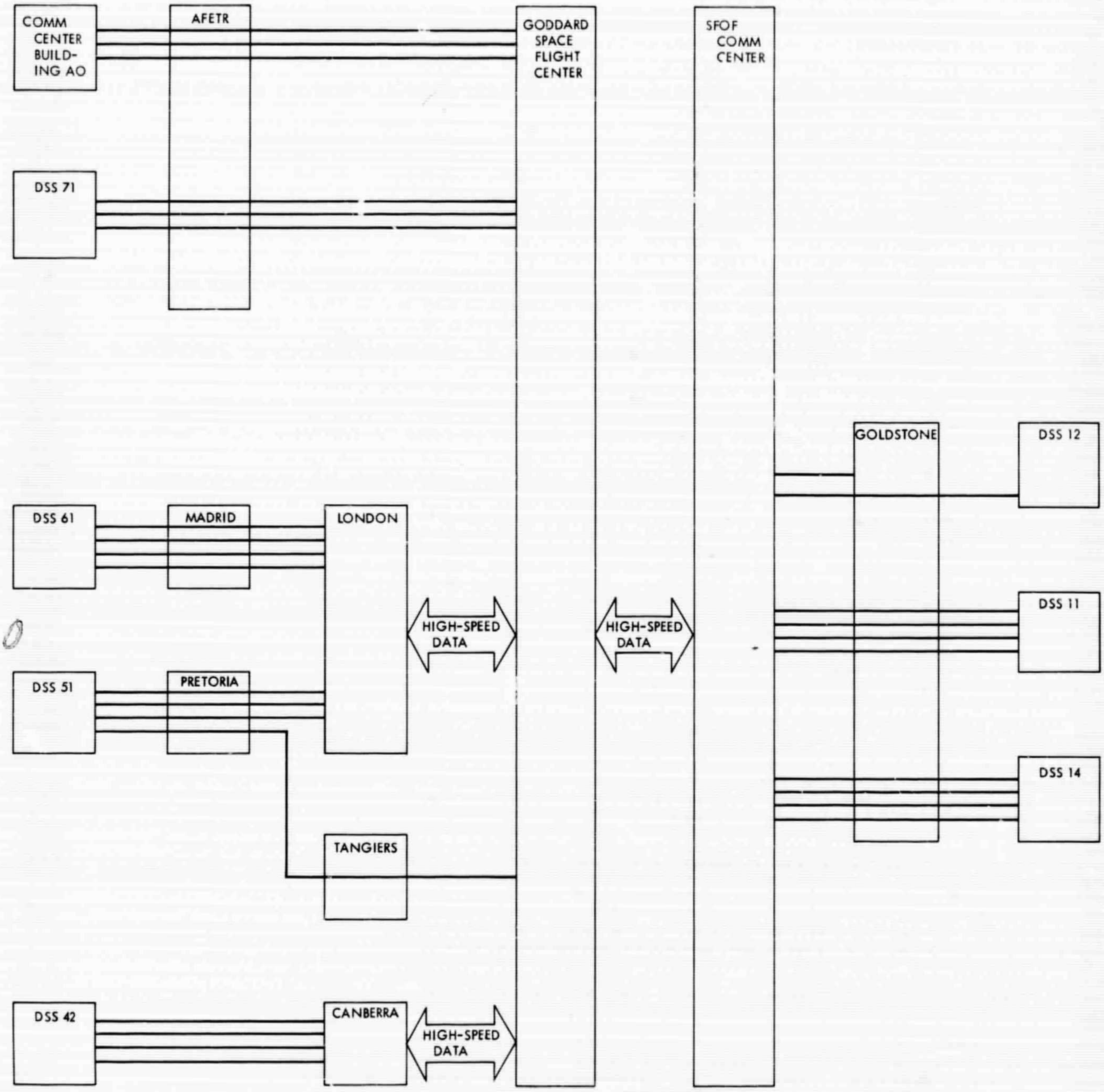


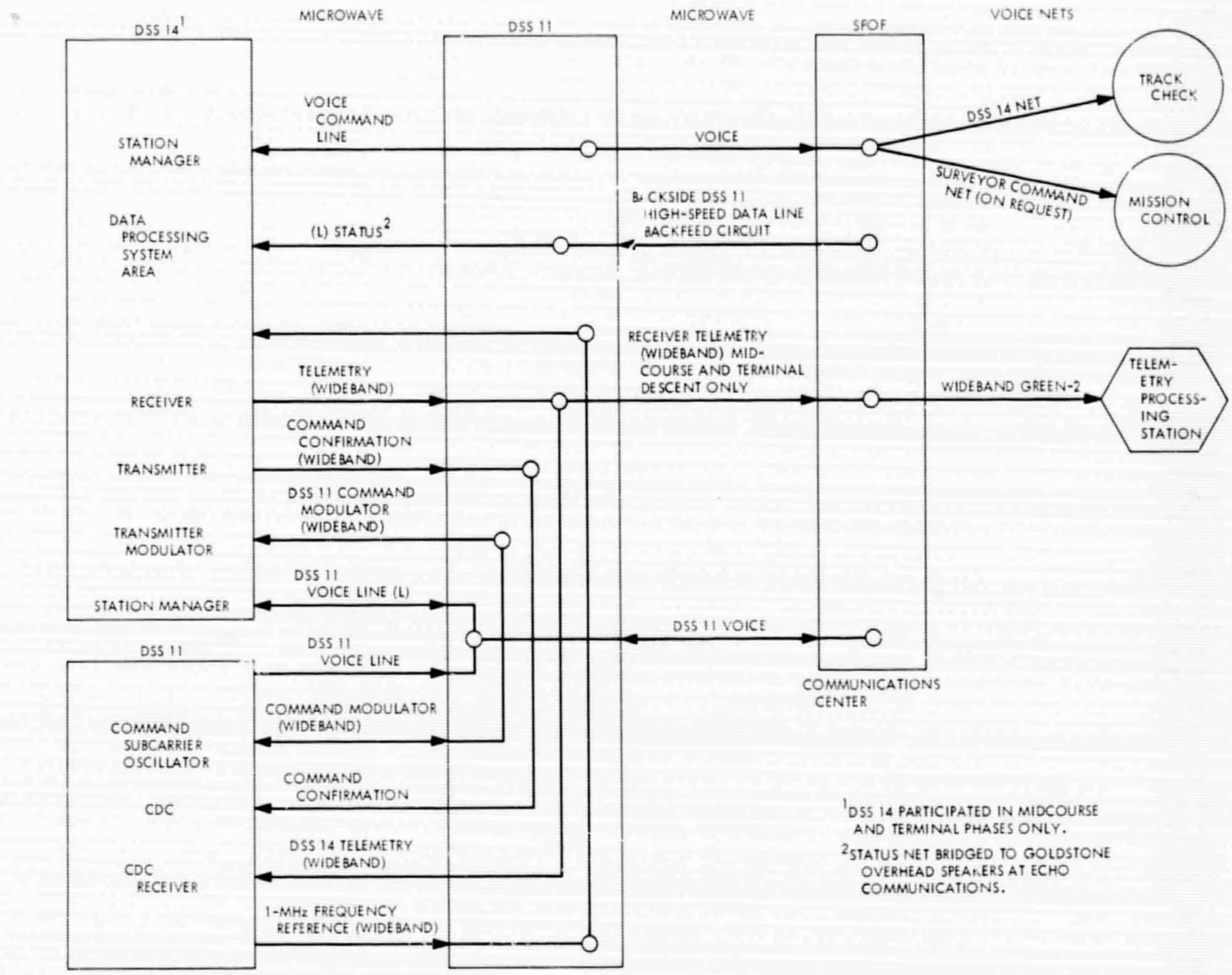
Fig. 21. NASCOM/GCF teletype routing for *Surveyor VII*

(3) The 7094 computer used in mode 4 to produce a magnetic tape containing the appropriate stations predicts. This magnetic tape was placed on the PDP-1 computer in the simulated data conversion center. The PDP-1 60-words/min output was patched direct to JPL communications, which speed changed to 100 words/min and retransmitted to the appropriate Deep Space Station.

(4) Commands were transmitted to the appropriate station via voice in the normal manner using the station voice line.

2. *Intracommunications system.*

a. General. The interacommunications system (ICS) is composed of the internal circuits and equipment re-



Circuit type/ mode	SFOF display designation	Direction of data (DSS–JPL)	Special circuit uses and remarks[a]
Voice	DSS 14 net	⟷	Station voice line. DSIF control traffic
Voice	DSS 11 net	⟵	DSS 11 voice line extended on (L) basis to allow DSS 14 to monitor voice commands to DSS 11
Video	None	DSS 14 to DSS 11	Wideband microwave channel used for DSS 14 command confirmation to DSS 11 CDC
Video	None	DSS 14 to DSS 11	Wideband microwave channel used for DSS 14 receiver. Spacecraft telemetry data to DSS 11 CDC receiver
Video	None	DSS 11 to DSS 14	Wideband microwave channel used for DSS 11 command modulation to DSS 14 transmitter
Wideband (96 kHz)	96 kHz	DSS 14 to DSS 11 and SFOF	Wideband microwave channel used for DSS 14 CDC receiver telemetry routed to Echo Communications, then split to DSS 11 CDC and SFOF telemetry processing station

[a]Standard configuration for midcourse and touchdown will be DSS 14 receiver telemetry to SFOF telemetry processing station via 96-kHz line.

Fig. 22. Space Flight Operations Facility/DSS 14 initial circuit configuration diagram

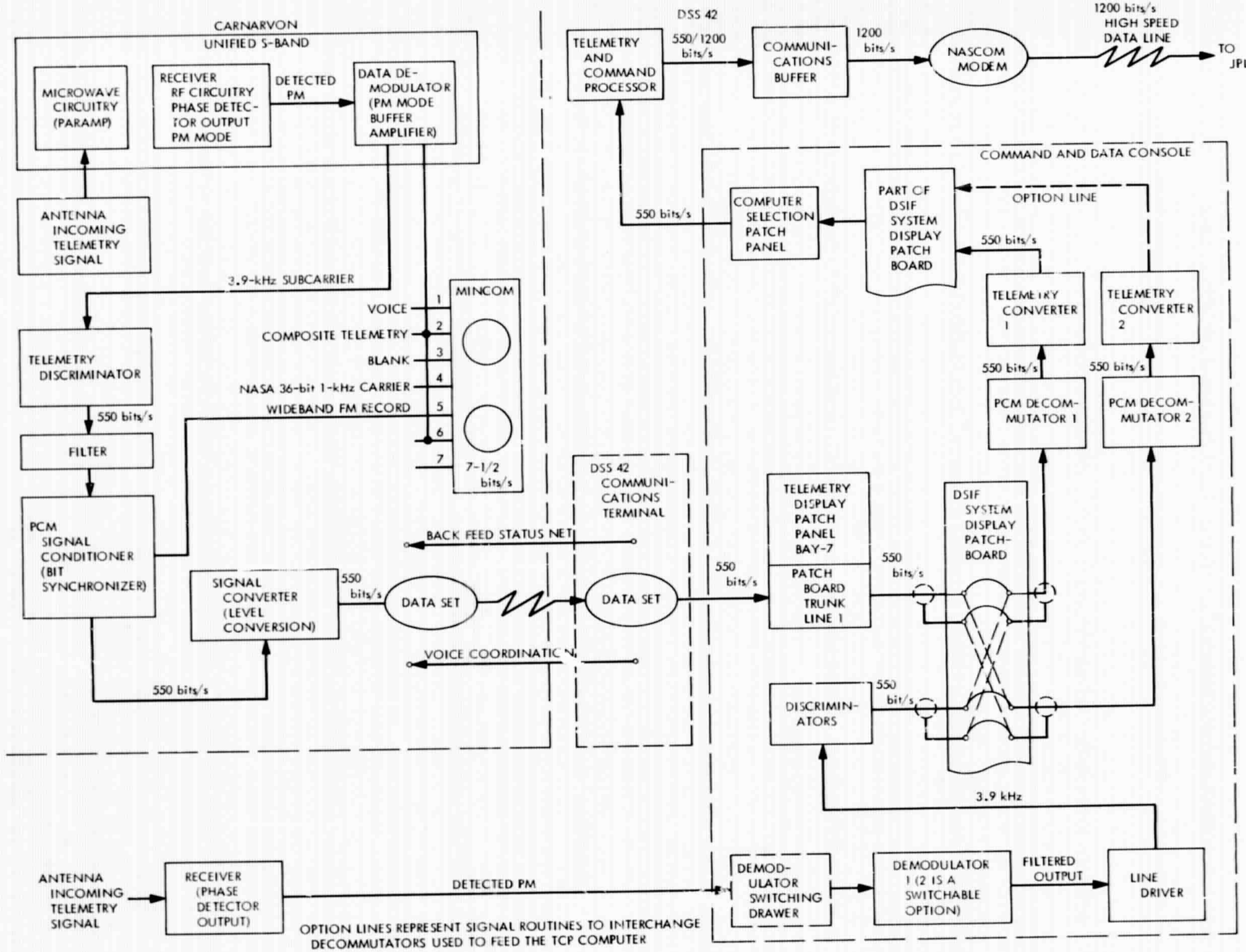


Fig. 23. Carnarvon/DSS 42 *Surveyor VII* spacecraft telemetry; circuit configuration

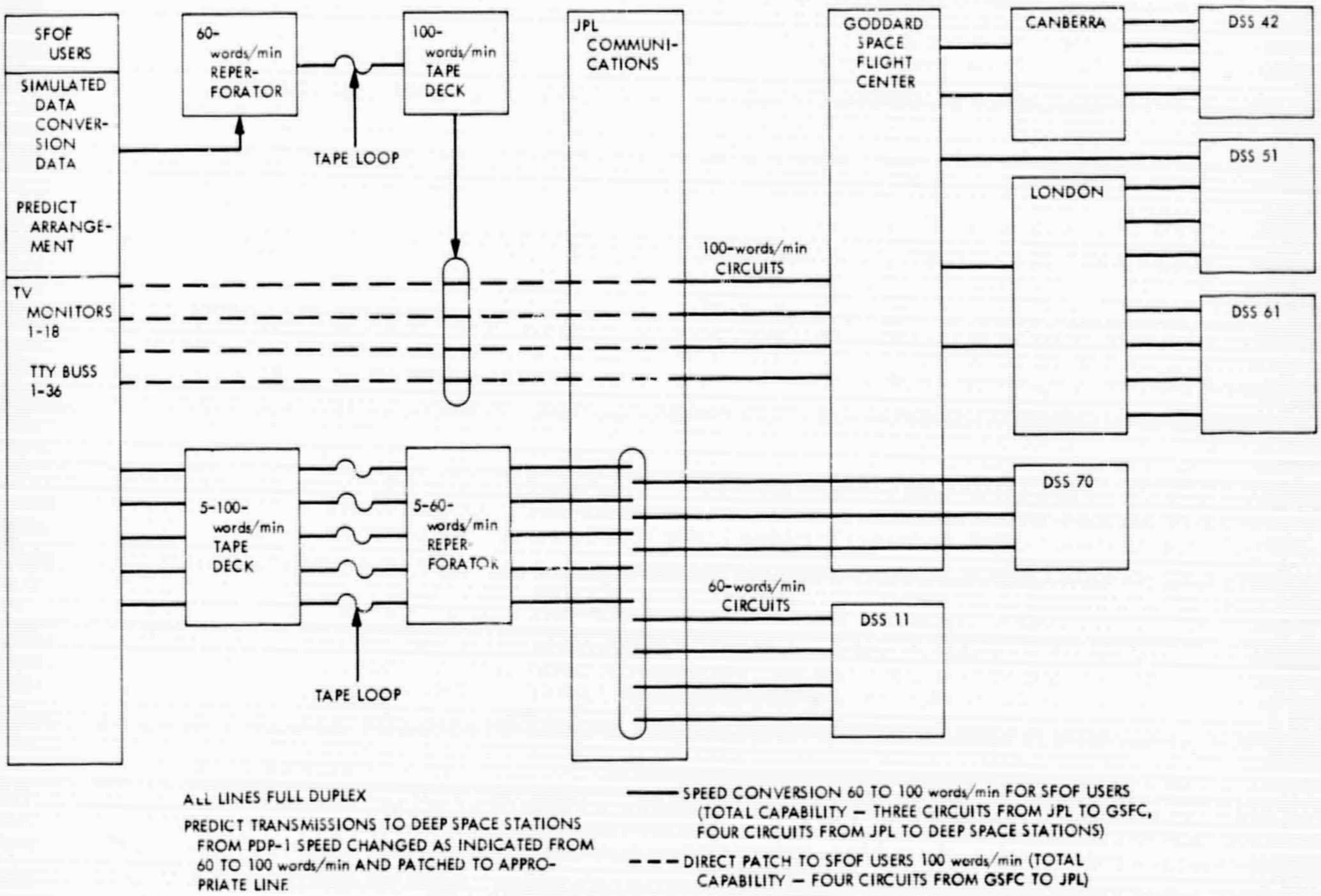


Fig. 24. Space Flight Operations Facility communication emergency hardware configuration capability

quired to provide an integrated, multipurpose, internal communications network for the support of all space flight missions and simulations conducted in the SFOF. Both special-purpose and conventional communications equipment are used. The majority of this communications equipment is owned by JPL; however, certain end items of equipment are leased from commercial sources. Details on configuration of the ICS are contained in the *Surveyor VII* Mission communications support plan.

b. Function. The three functions of the ICS are discussed in the following paragraphs:

(1) To provide an end terminal and switching capability for NASCOM and other special purpose circuits external to the SFOF. In this respect, the capability of receiving voice, teletype, high-speed, and wideband data from the various data acquisition stations through the DSN/GCF exists in the ICS. The capability also exists to transmit voice, teletype, and high-speed and wideband data from the SFOF to various external terminals.

(2) To provide a means whereby incoming data to the SFOF may be properly routed to user areas throughout the SFOF. In this respect, the capability of distributing such data through audio and video means exists in the ICS.

(3) To provide a means whereby user areas of the SFOF are interconnected. In this respect, the capability of transmitting and receiving through audio and visual means exists in the ICS.

c. Composition. The ICS is composed of the following subsystems:

(1) Operational voice communications subsystem.

(2) Operational status recording subsystem.

(3) Operational public address subsystem.

(4) Operational voice recording subsystem.

(5) Operational miscellaneous audio subsystem.

(6) Operational teletype communications subsystem.

(7) Television communications subsystem.

(8) High-speed data subsystem.

(9) Wideband communications subsystem.

d. Status. DSN communications control provides three status displays used to inform users about communications circuits activated in support of flight projects. These displays can be observed on the television communications subsystem and consist of the following:

(1) Teletype status display.

(2) Audio status display.

(3) Propagation status display.

e. Scheduling. Portions of the ICS are available for use 24 h per day; other portions, however, must be scheduled through the use of SFOF Form 1-A. The internal communications requirements, and the SFOF requirements should be stated on this form. The SFOF Form 1-A should then be submitted to the DSN operations control chief.

f. Interfaces. The DSN communications center includes many operational interfaces of various types and quantities of circuits. They are:

(1) NASA Communications System.

(2) User areas.

(3) Simulation data conversion center.

(4) Telemetry processing station.

(5) Data processing system.

(6) Television ground data handling system.

(7) Public information office.

D. Space Flight Operations Facility

The SFOF is comprised of three major systems:

(1) Data processing system.

(2) Intracommunications system.

(3) Support system.

1. Area configurations. The SFOF areas committed to support the *Surveyor VII* Mission were configured as shown in Figs. 25–29. These areas were:

(1) Data control area.

(2) Mission support area 1A.

(3) Mission support area 1B.

(4) Flight path analysis area 1.

(5) DSN operations area.

Other SFOF areas supporting *Surveyor VII* were:

(1) Data processing area (Fig. 30).

(2) Telemetry processing station (Fig. 31).

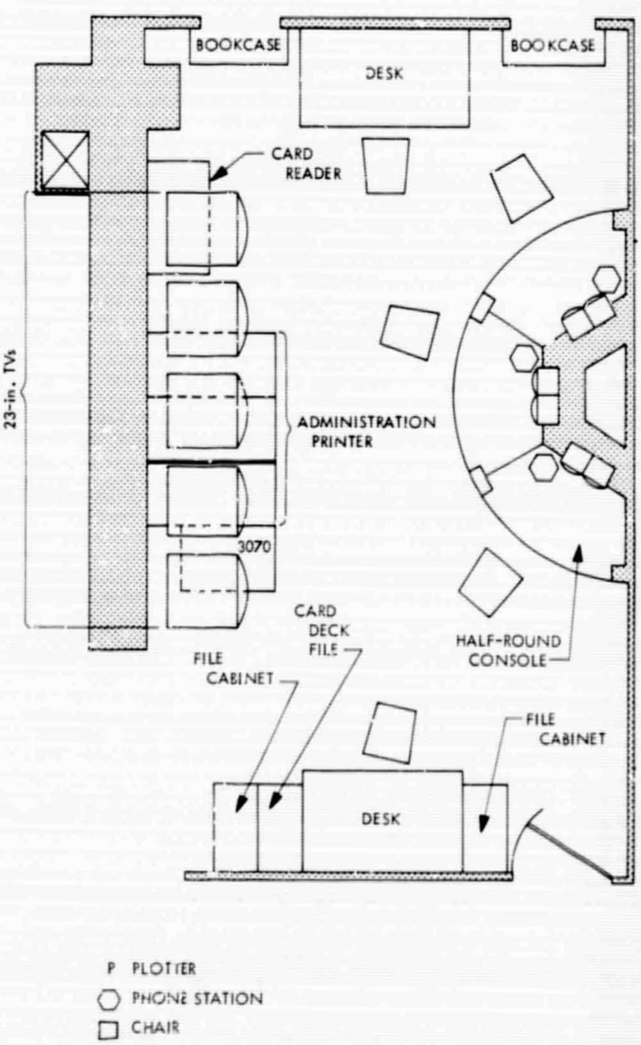


Fig. 25. Data communications area (230-104)

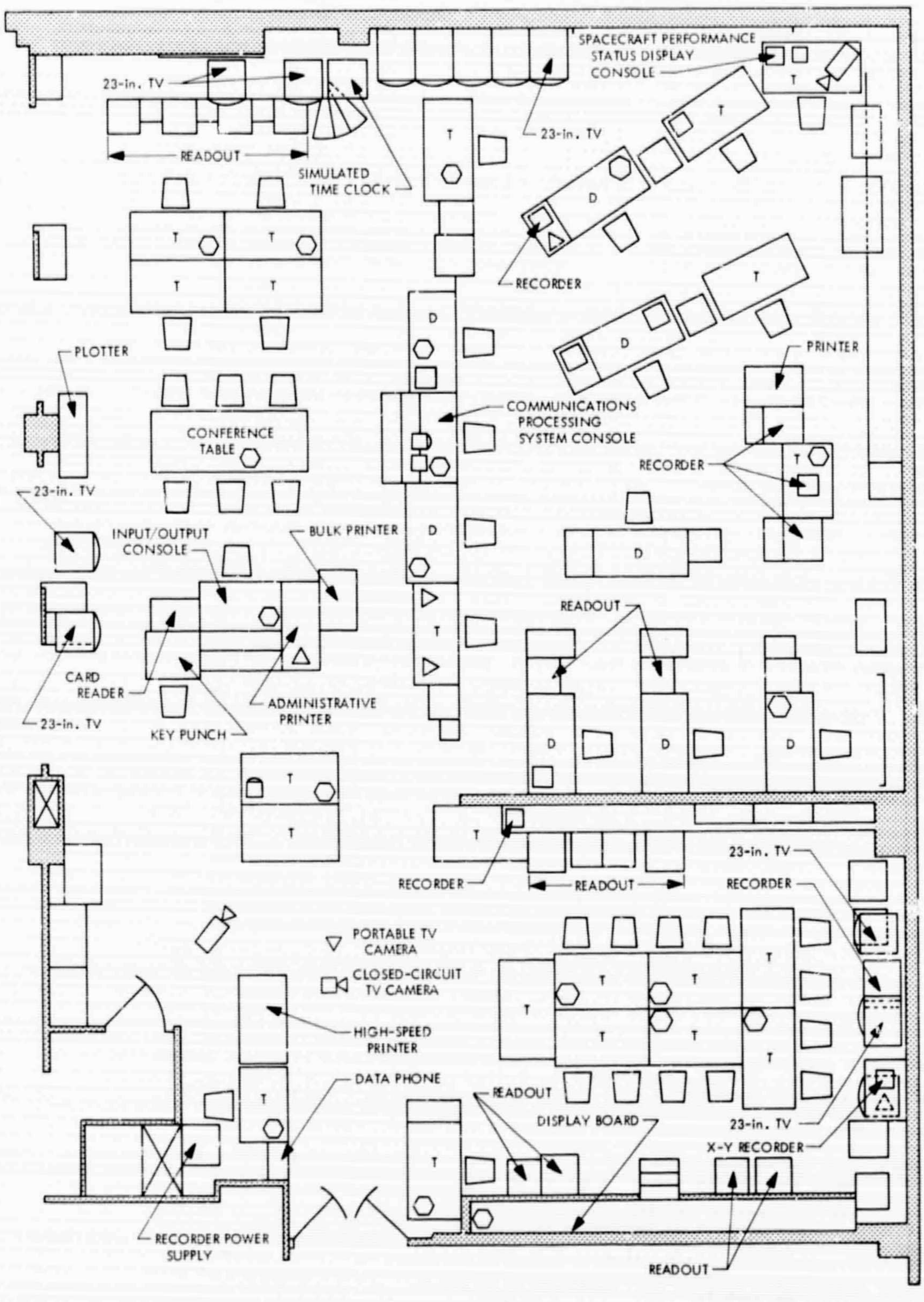


Fig. 26. Mission support area 1A (spacecraft performance analysis area)

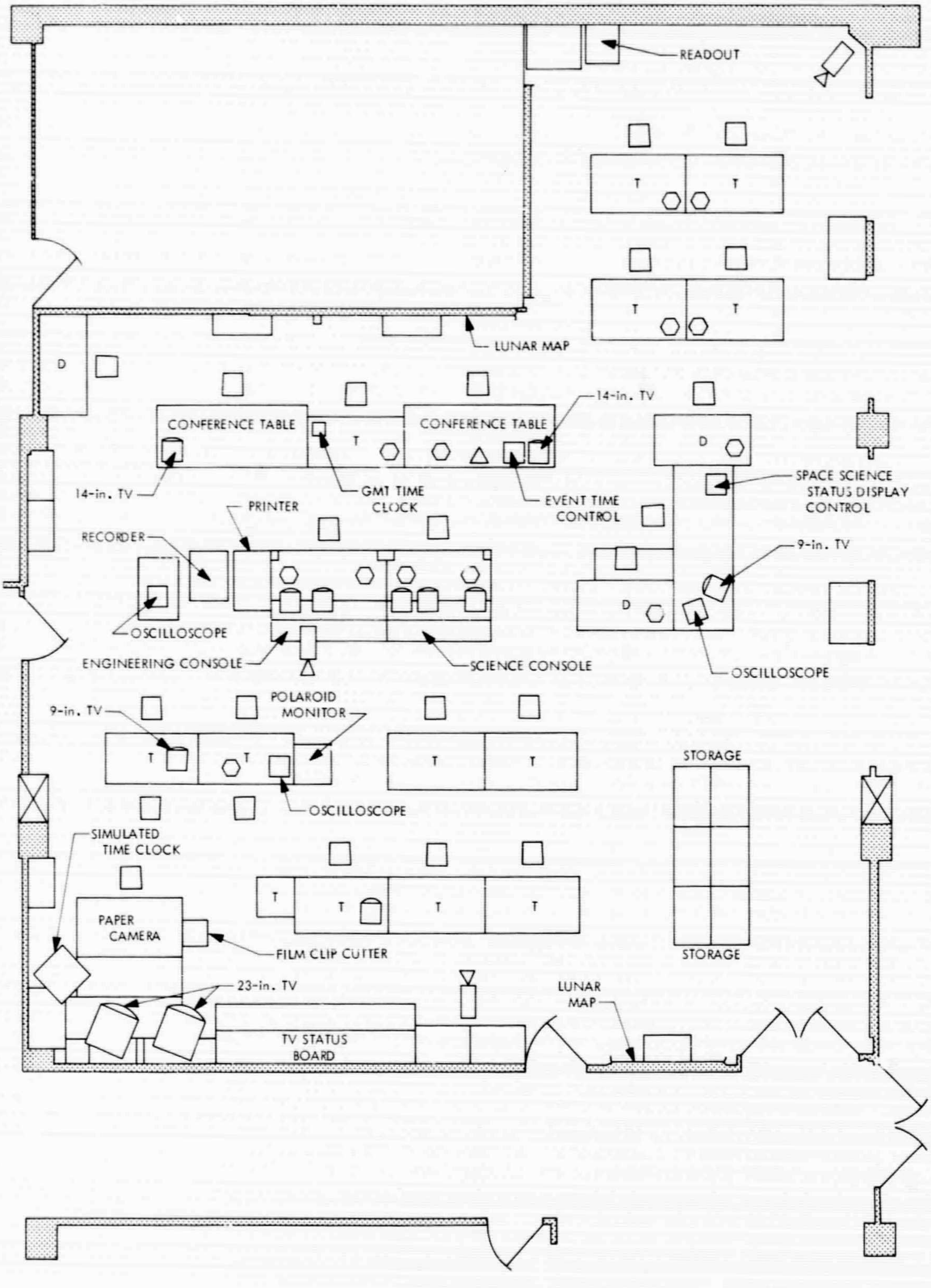


Fig. 27. Mission support area 1B (space science analysis area)

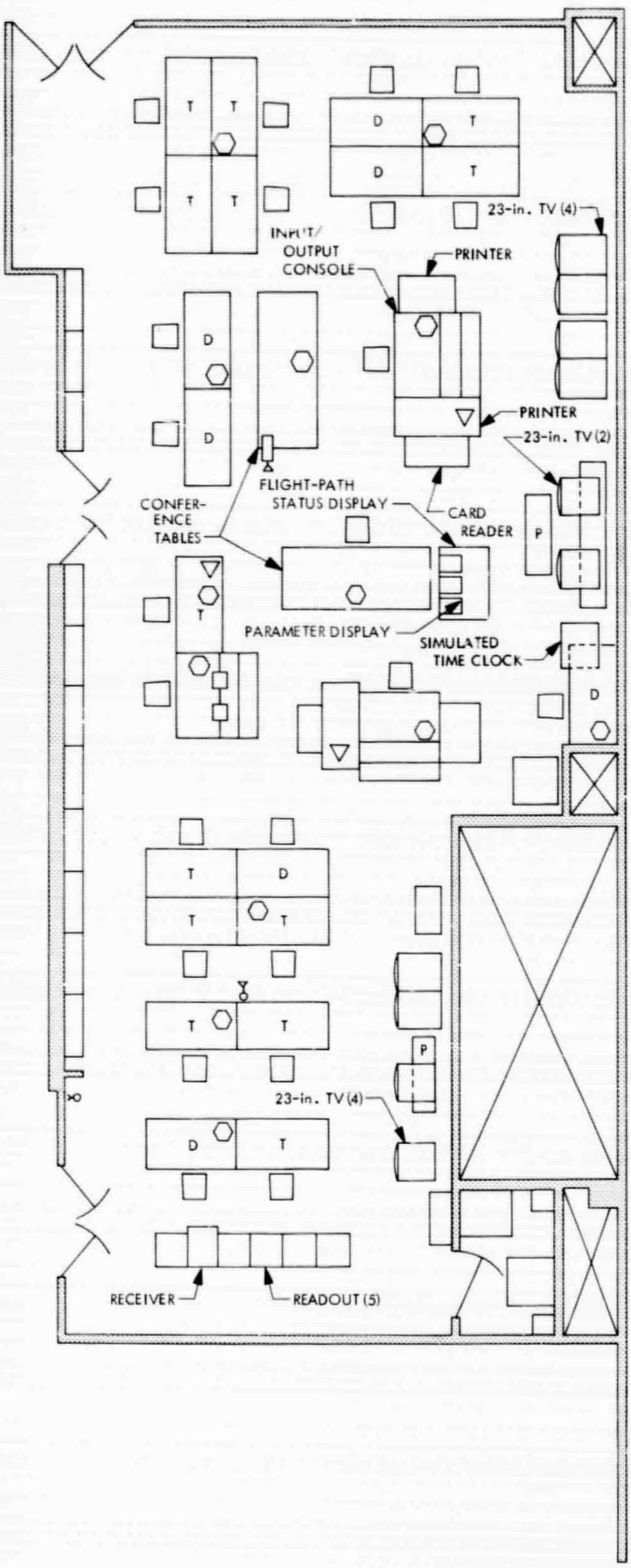


Fig. 28. Flight path analysis area 1

(3) *Surveyor* science evaluation and analysis team room (Fig. 32).

2. Support system description. The various support systems configured for or used by the *Surveyor* Project are described in the following paragraphs.

a. SFOF document control. The SFOF document control provides the required services for handling and microfilming the flight data. Document control is located on the third floor of the SFOF. Data handling is defined in mission-independent SFOF standard operations procedures.

b. SFOF reproduction area. Services were available to the *Surveyor* Project for reproduction of flight data from computer printouts under near-real- and non-real-time conditions.

c. Display subsystem. Displays were provided for project use in each of the areas, as described in the following paragraphs:

(1) The mission display board display equipment consisted of two Eidophor projectors, two teleprompter projectors, four sets of mission display projectors, four sets of special time displays (countdown/up clocks), and miscellaneous supporting display equipment.

(2) Displays in the flight path analysis area included: the maneuver board, orbital and miss parameters board, tracking data board, and trajectory display board. Chalkboards and/or bulletin boards were also provided.

(3) The display in the spacecraft performance analysis area was a spacecraft telemetry measurement display board (preformatted chalkboard). Chalkboards and/or bulletin boards were also provided.

(4) Displays in the space science analysis area included the TV identification display board, and chalkboards and/or bulletin boards for project use.

d. Project publications. Project publications provided support for space flight operations through the preparation of mission-independent documents, such as standard operating procedures, standard maintenance procedures, engineering technical memorandums, etc.

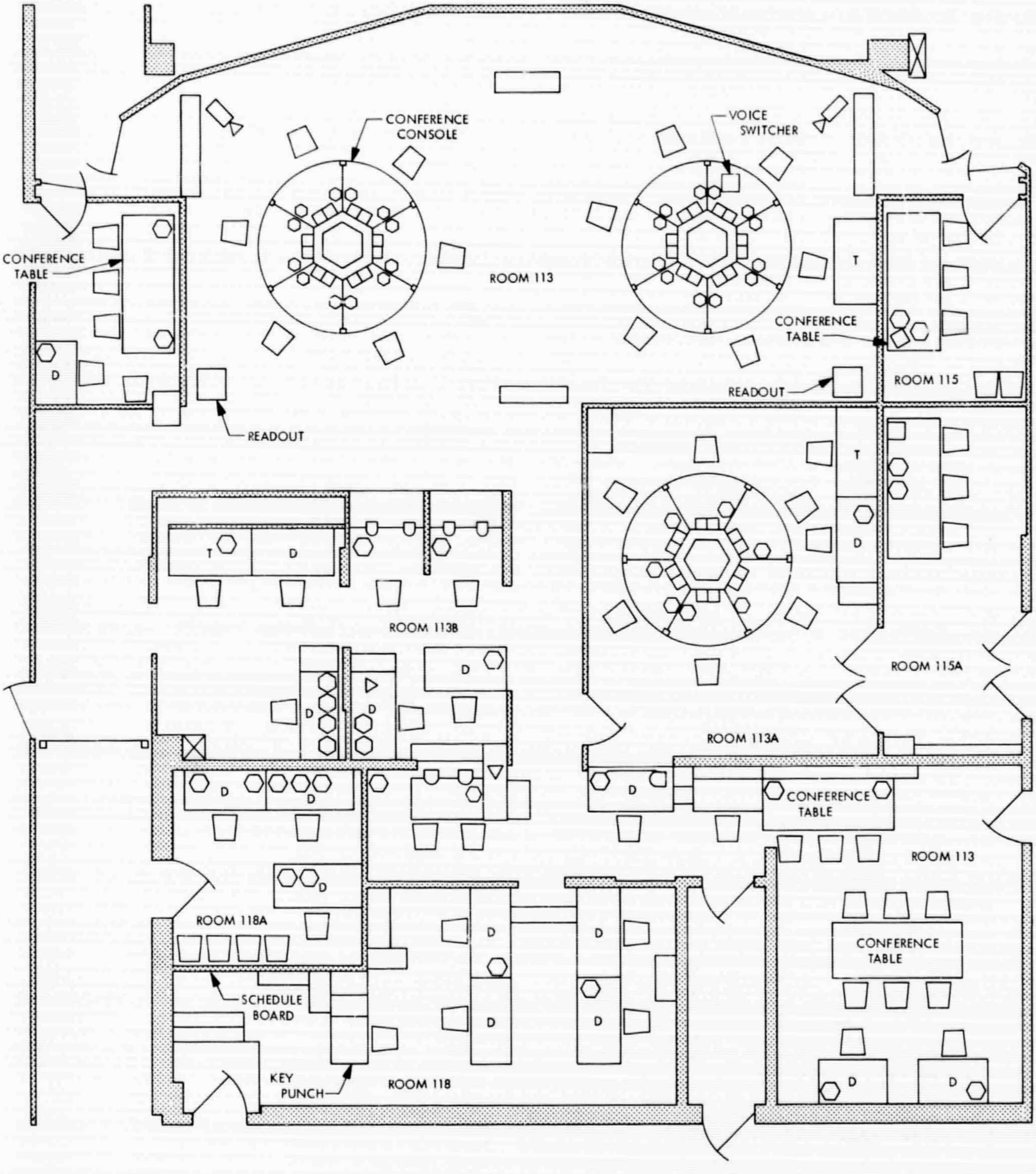


Fig. 29. Deep Space Network Operations area

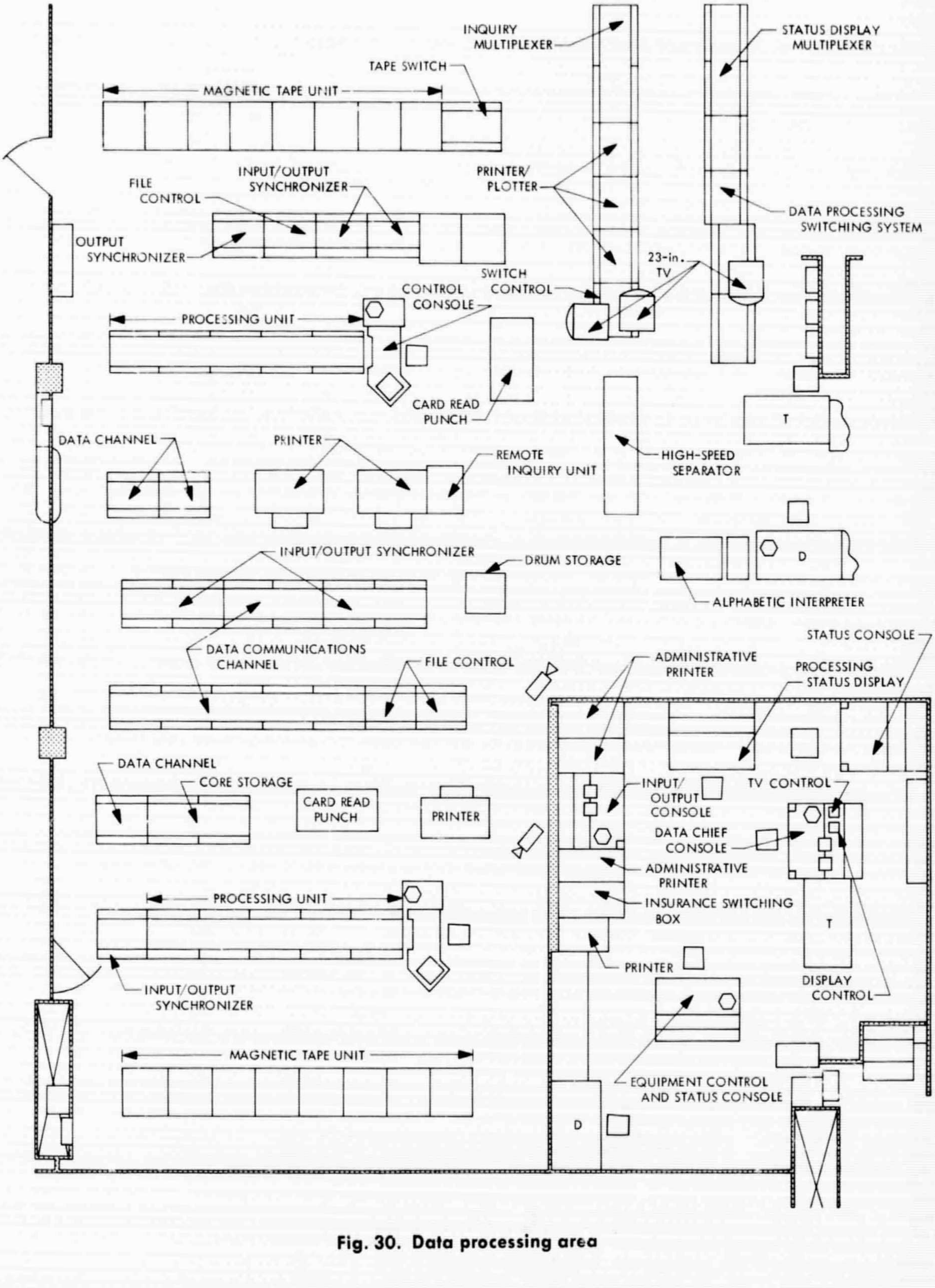


Fig. 30. Data processing area

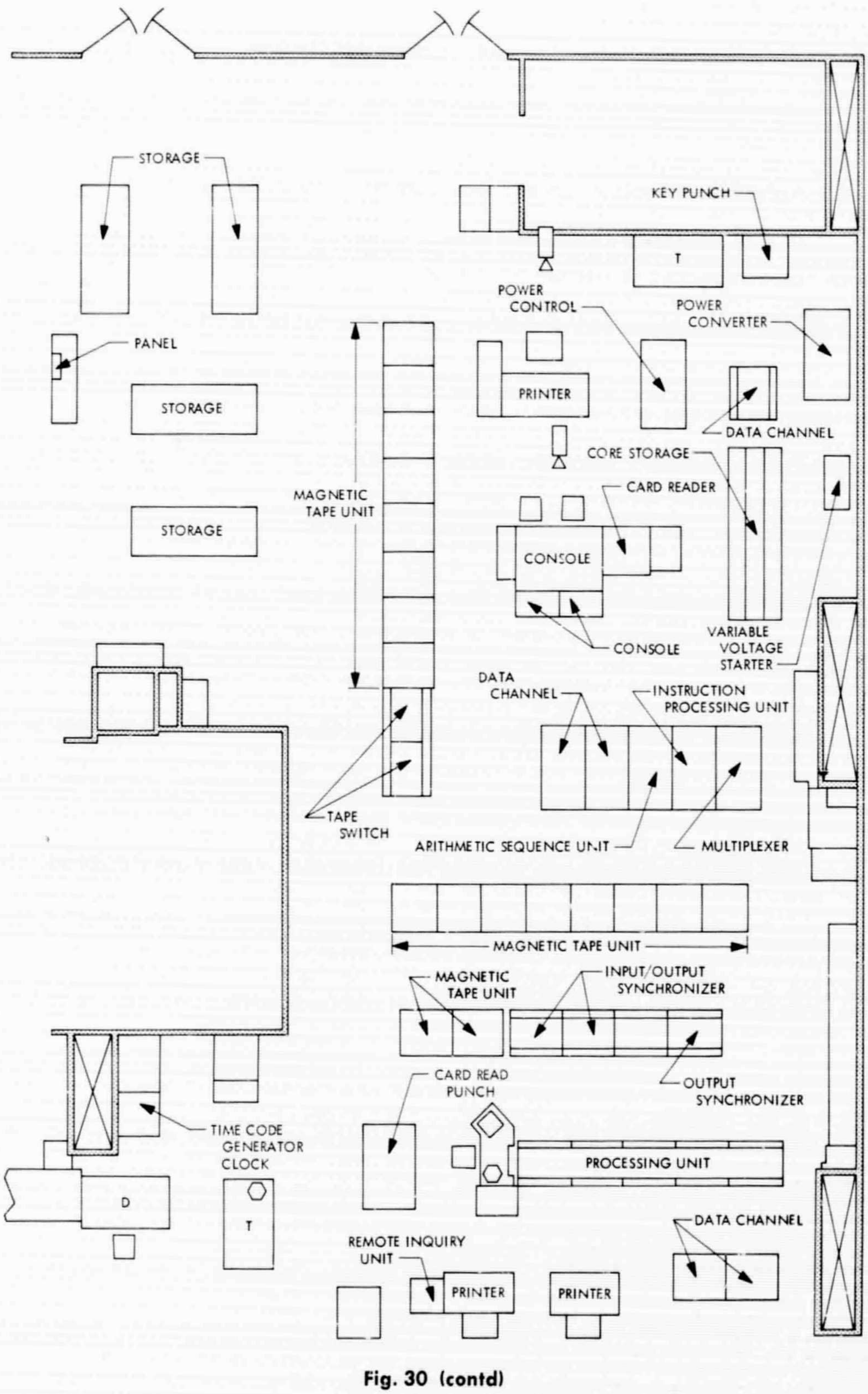
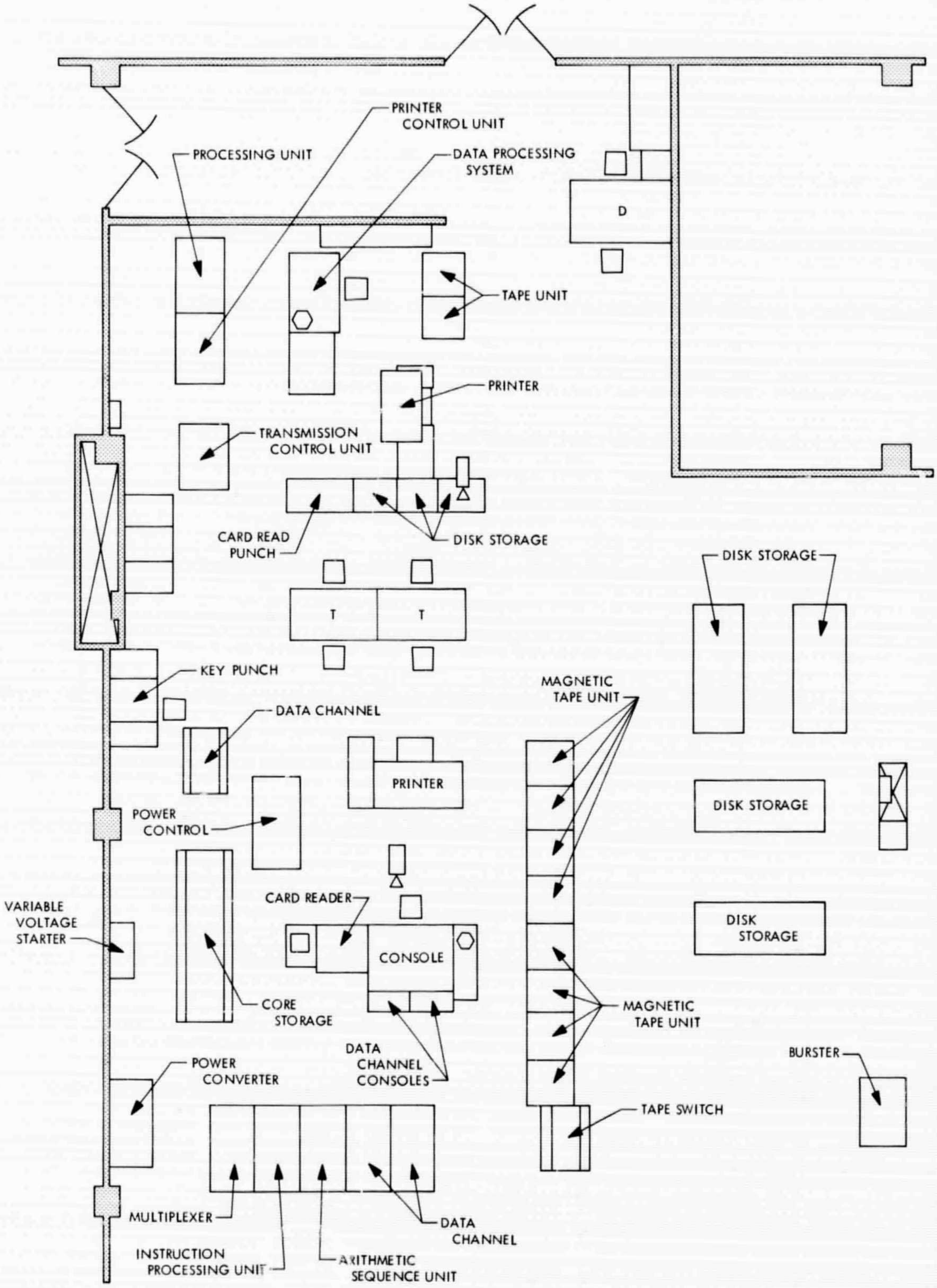

STORAGE
KEY PUNCH
T
POWER CONTROL
POWER CONVERTER
PANEL
PRINTER
STORAGE
DATA CHANNEL
CORE STORAGE
MAGNETIC TAPE UNIT
CARD READER
STORAGE
CONSOLE
CONSOLE
VARIABLE VOLTAGE STARTER
DATA CHANNEL
INSTRUCTION PROCESSING UNIT
TAPE SWITCH
ARITHMETIC SEQUENCE UNIT
MULTIPLEXER
MAGNETIC TAPE UNIT
MAGNETIC TAPE UNIT
INPUT/OUTPUT SYNCHRONIZER
CARD READ PUNCH
OUTPUT SYNCHRONIZER
TIME CODE GENERATOR CLOCK
PROCESSING UNIT
D
T
DATA CHANNEL
REMOTE INQUIRY UNIT
PRINTER
PRINTER

Fig. 30 (contd)


PRINTER CONTROL UNIT
PROCESSING UNIT
DATA PROCESSING SYSTEM
D
TAPE UNIT
PRINTER
TRANSMISSION CONTROL UNIT
CARD READ PUNCH
DISK STORAGE
DISK STORAGE
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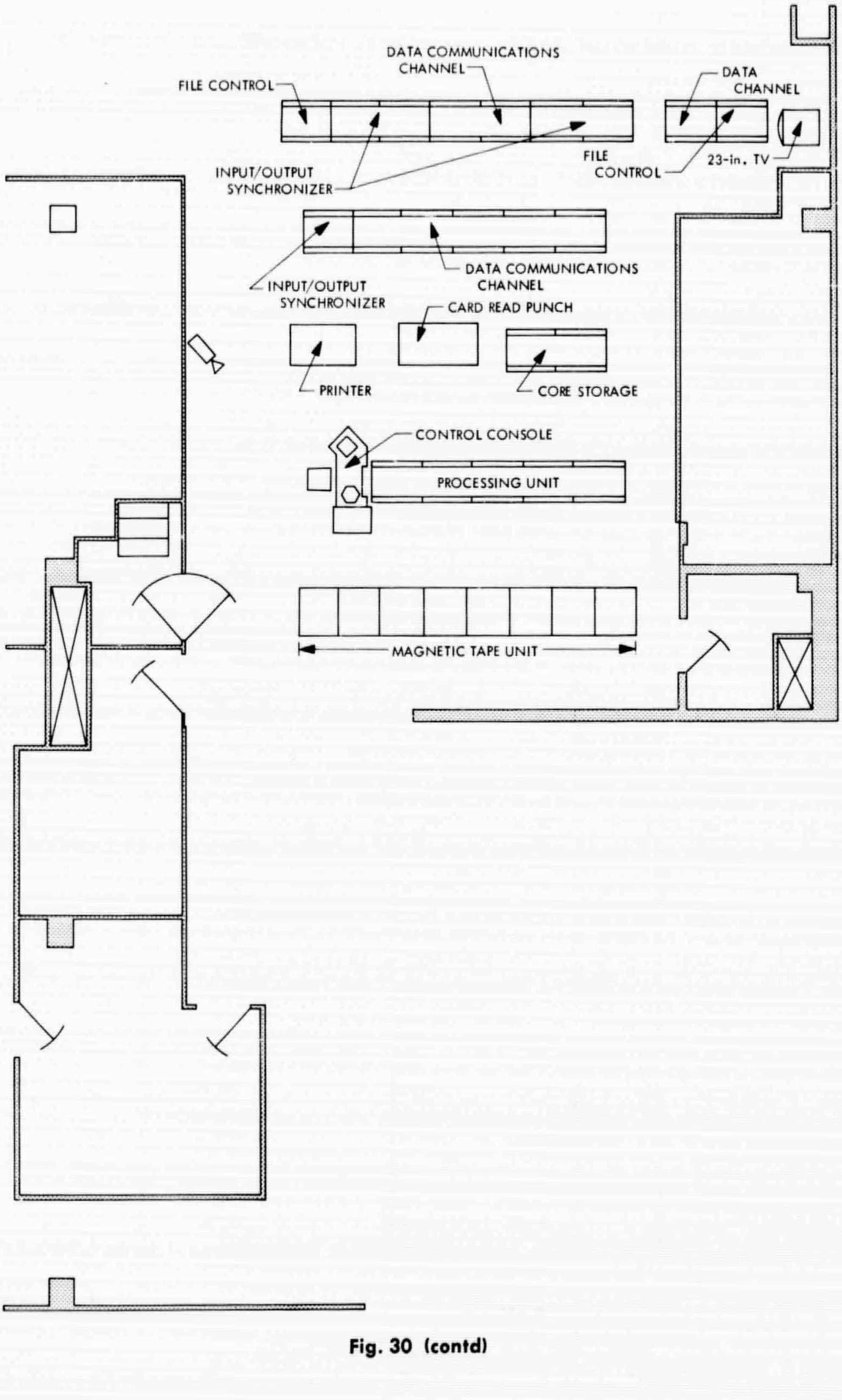
T
KEY PUNCH
MAGNETIC TAPE UNIT
DATA CHANNEL
PRINTER
DISK STORAGE
POWER CONTROL
CARD READER
DISK STORAGE
VARIABLE VOLTAGE STARTER
CONSOLE
CORE STORAGE
MAGNETIC TAPE UNIT
DATA CHANNEL CONSOLES
BURSTER
POWER CONVERTER
TAPE SWITCH
MULTIPLEXER
DATA CHANNEL
INSTRUCTION PROCESSING UNIT
ARITHMETIC SEQUENCE UNIT

Fig. 30 (contd)



DATA COMMUNICATIONS
CHANNEL
FILE CONTROL
DATA
CHANNEL
FILE
CONTROL
23-in. TV
INPUT/OUTPUT
SYNCHRONIZER
DATA COMMUNICATIONS
CHANNEL
INPUT/OUTPUT
SYNCHRONIZER
CARD READ PUNCH
PRINTER
CORE STORAGE
CONTROL CONSOLE
PROCESSING UNIT
MAGNETIC TAPE UNIT

Fig. 30 (contd)

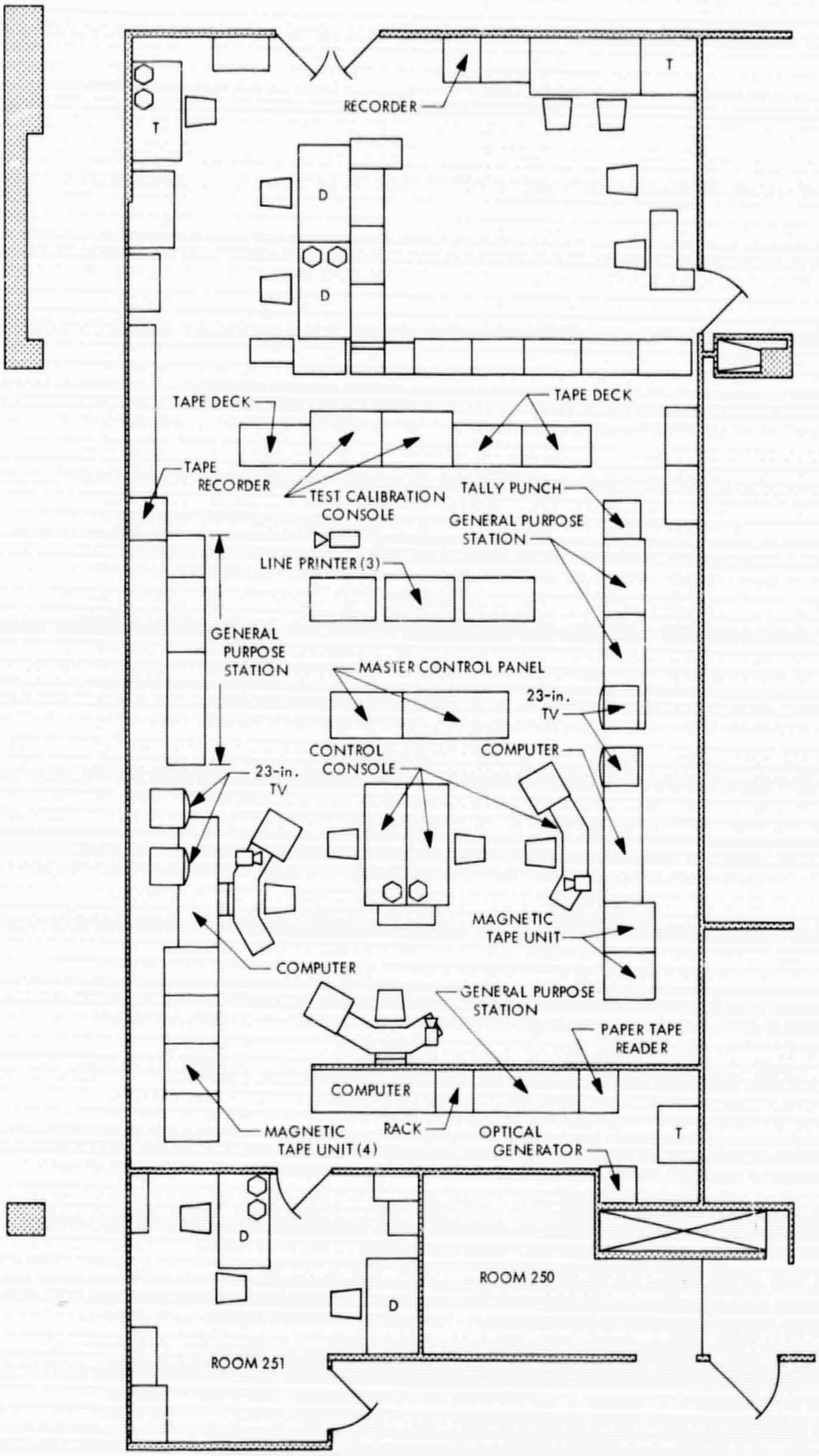


Fig. 31. Telemetry processing station

e. Support services. Special support functions and services were available to the project as follows:

(1) SFOF status phone. Information concerning SFOF access (i.e., type of badge required for admittance) was provided 24 h/day by means of a mission-independent status recording. This status recording was automatically played back. Mission status information was obtained from the *Surveyor* Project status recording.

(2) Generation of a DSN sequence of events.

(3) Headsets, handsets, Y boxes, and extension cords.

(4) Access control.

(5) Technical area assistance and supplies.

(6) Cafeteria arrangements for flight operations personnel.

(7) Coffee arrangements for flight operations personnel.

(8) SFOF special transportation.

(9) Discrepancy reporting.

3. *Data processing system.* The data processing system of the SFOF was comprised of three hardware groups:

(1) Computer equipment.

(2) Input/output equipment.

(3) Telemetry processing station equipment.

a. Hardware. The data processing system hardware groups and their area locations and references were as follows:

Group	Location
Computer equipment	Second floor, SFOF (area L)
Input/output equipment	Flight path analysis area Mission support area 1A Mission support area 1B Data processing control area
Telemetry processing station equipment	Second floor, SFOF (area H)

b. Software (computer programs). The SFOF provided the following mission-independent, DSN computer programs in support of *Surveyor VII*:

(1) IBM 7040 print program for listing magnetic tapes.

(2) IBM 7094 IBSYS monitor for compiling, assembling, and running programs.

(3) IBM customer engineering diagnostics for system checkout.

c. Computer equipment. The computer equipment was set up as follows:

(1) The W, X, and Y computer strings were placed in the stand-alone condition as directed in the SFOF direct couple operating system/stand-alone configuration switching procedure.

(2) The extended memory switch on the IBM 7044W and IBM 7044X were placed in the 32K position in accordance with the SFOF extended memory switching procedure.

d. Input/output equipment. The input/output equipment was set up as described in the following SFOF standard operating procedure:

(1) Message composer and status display (input message composer and status display).

(2) Administrative printer (administrative printer).

(3) 3070 bulk printer (bulk printer).

(4) 30×30-in. plotter (Milgo 30×30-in. plotter).

(5) Card reader (Burroughs B-122 card reader).

(6) As required by *Surveyor VII*, the data chief switched input/output equipment between the W, X, and Y strings in accordance with equipment switching procedures.

e. Telemetry processing station equipment. Telemetry processing station equipment was set up and verified for *Surveyor* as described in the telemetry processing station real-time setup procedures.

f. Changes from Surveyor VI. The W string computers were prime for *Surveyor VII*. This is a new combination of the former W and V computers but there was no change in capability.

The X string backed up the W string for *Surveyor VI*. All preventive maintenance was completed 1.5 h prior to the ORT, January 5, 1968.

4. Support system. Technical area assistant support was limited to two assistants for the ORT, two for the flight, and one assistant after touchdown. Access control remained the same as that for *Surveyor VI*.

A new operations area display capability existed for support of *Surveyor VII*. Six prepared slides formed the basis for the only requests received for this display. They included:

(1) A map display of the anticipated near-earth track showing AFETR/MSFN stations and including a table of times for acquisition and loss of signal.

(2) Two slides listing *mark* numbers 1–26 with provision of dynamic checkoff as each *mark* was achieved. No time was shown.

(3) A slide of DSIF view periods with provision for dynamic pictorialization of one- and two-way lock at each station.

(4) A slide giving dynamic status of project utilization of the data processing system.

(5) A slide presenting a nominal sequence of events.

E. Tests

The *Surveyor VII* Mission required testing support to ensure mission success. The various classes of test and actual testing performed are described in the paragraphs that follow.

1. Air Force Eastern Test Range/GSFC testing. Two TDS tests were scheduled prior to the full project ORT, which was conducted on January 5, 1968. These tests are described below.

The first test, on December 20, 1967, was performed to ensure that the use of the communications satellite circuits from Ascension Island to the SFOF and AFETR for spacecraft telemetry data (550 bits/s) and metric tracking data, respectively, were compatible with the data transmission system.

The telemetry processing station at the SFOF was used to verify the spacecraft data; the test was considered successful.

The second test, conducted on December 28, was performed to ensure the readiness of the AFETR and MSFN TDS stations to support the final ORT and launch.

No serious problems were encountered and all systems performed satisfactorily, with the exception of Antigua, which lost tracking data because of a problem with a computer. Data were back on line at approximately $T + 10$ min.

All elements of the near-earth TDS participated in the project ORT, which was conducted on January 5, 1968. No serious problems were encountered, and the TDS was considered ready to support the launch.

There were no unresolved problems prior to launch.

The MSFN participated in two simulations in support of the AC-15 mission. The first simulation went smoothly except for the telemetry data flow test from Tananarive.

The yaw rate measurement did not read as anticipated, apparently because of a faulty test tape. However, the yaw rate was determined by using a tunable discriminator in lieu of the fixed discriminator.

No applicable problems occurred during the second simulation.

During the launch phase Tananarive experienced difficulty with the serial decimal time equipment; the day of the year was in error, but hours, minutes and seconds were correct. However, an instrumentation support instruction was originated and transmitted via teletype to Tananarive containing the information to be entered on the tape labels. Upon receipt of the instruction, the station took appropriate action to note on tape labels that day of year was in error prior to shipment.

Carnarvon did not receive the final network operations plan prior to launch although all required support was provided by utilizing the draft network operations plans, premission documentation changes, and instructions.

2. Deep Space Network. The DSN supported the *Surveyor* Project test plan, which included various operational, compatibility, and integration tests. The following paragraphs define the tests conducted in preparation for the *Surveyor VII* flight.

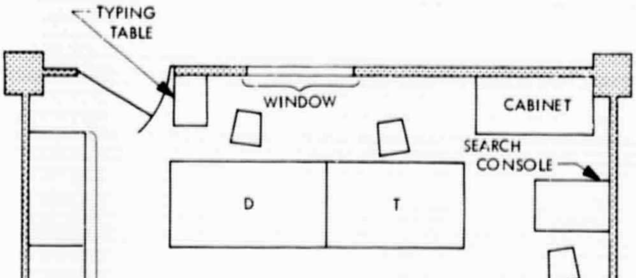


Fig. 32. Surveyor science evaluation and analysis team

The A (facility internal) tests were scheduled and conducted by each station manager and involved only the individual station. (There was no GCF SFOF participation.) The A tests utilized the standard sequence of events and were employed by the station as a countdown exercise. The two test phases were as follows: those that prepare the station for B tests and those that were designated to train for C tests. Both test phases developed the ability of personnel to use the proper procedures and hardware within a given time constraint. All prime stations completed sequences of A tests. The stations continually perform significant sequences in the A tests for practice, station countdown, and training of new people.

The B (functional compatibility) tests were designed to ensure that ground based facilities were capable of processing telemetry data and video data (DSS 11 only) as received from the spacecraft. Command capability was also verified in all configurations and modes of operation. The sequence of events was also incorporated into this series. Because the B tests were not performed in real-times, it was not necessary to rigidly adhere to the operational procedures. During these tests, data were sent from the prime and support stations to the SFOF for processing, and full mission support in the SFOF was required.

The purpose of the C (operational) tests was to verify that all prime and support stations, communications and the SFOF were fully prepared to meet *Surveyor VII* responsibility. Selected portions of the sequence of events were followed rigidly, using both standard and nonstandard procedures.

Compatibility tests were run between the test spacecraft (T-21), and the prime Deep Space Stations, Deep Space Communications Complex, CDC, and the SFOF, to establish mutual compatibility between all of these elements of the network. The tests included RF tests, command tests, and telemetry tests.

DSS back-up and stations under engineering cognizance conducted training tests for operator crews. The T-21 was used for Space Science Analysis and Command/SPAC lunar sequence training and as a data source for B and C tests with DSS 11 only.

Tests were conducted to check out the *Surveyor* on-site computer program (SOCP) and to verify data that could be transmitted from a DSIF station of the SFOF and be processed there. Such tests were run on a regular basis with each prime station. These tests were concluded with a checkout of the final mission version of the SOCP program.

a. Test summary. The test program prior to the launch of *Surveyor VII* consisted of two operational tests. The primary objective of these tests was to ensure that all elements of the DSN, including the technical and operational personnel, were capable of totally supporting the mission in accordance with the *Surveyor* flight operational plan. Class C tests:

(1) Utilized the full complement of personnel required for *Surveyor* flight operations.

(2) Included standard operational procedures and heavily emphasized nonstandard operational procedures.

(3) Required handling, processing, and interpretation of the full range of mission data under conditions of normal and degraded communications.

(4) Generally established the operational readiness of the DSN for the *Surveyor* mission.

b. Flight training test. The objective of the flight training test was to maintain and improve the efficiency of the personnel within the SFOF and selected portions of the DSN. Particular emphasis was placed on the critical portions of the mission that occur during the transit phase. The test was conducted in two segments covering the midcourse (M), terminal descent, retroignition (R), and touchdown (TD) events:

(1) Midcourse: $M - 2$ h, 45 min to $M + 20$ min

(2) Terminal: $R - 2$ h, 45 min to $TD + 36$ min

A summary of operational tests conducted prior to *Surveyor VII* Mission is shown in Table 12.

Table 12. Summary of tests conducted prior to Surveyor VII launch

Test	December 1967				January 1968				
	Week								
	4	11	18	25	1	8	15	22	29
Flight training		Δ							
Operational readiness					Δ				

Both midcourse and terminal descent segments of the test were accomplished on the same day (December 12, 1967). In each segment, spacecraft and/or station ground system problems were simulated by the test conductor and simulation team.

In the midcourse phase, the following two failures were simulated:

(1) Timing failure at DSS 11 time code generator from midcourse -45 min to test completion

(2) Spacecraft flight control programmer register failure

At midcourse -45 min, when the command message was being sent to DSS 11, the station reported a 1-pulse/s code failure from the station astronomical time code generator, rendering the on-site data processing equipment (910 and 920 computers) data handling functions, as well as the mission countdown clocks throughout the station, inoperative. This failure was not repaired until after the midcourse portion was called off.

The spacecraft magnitude register would not accept the maneuver quantity commands during the midcourse maneuvers in preparation for thrusting. SPAC requested a delay in midcourse in order to study the problem further. This was disapproved by mission control, and a sequence for manual execution of the maneuver was prepared by SPAC. This segment of the test was terminated without performing the midcourse maneuver.

In the terminal phase, the simulated failures were:

(1) Vernier lines heater failure at $R + 2$ h.

(2) DSS 11 operational voice communications subsystem net failure at $R - 1$ h.

(3) Flight control programmer register failure at $R - 7$ h.

The vernier line heater 2 failure was correctly diagnosed at $R - 1\frac{1}{2}$ h as a result of spacecraft signals P-4 (vernier line 2 temperature) steadily decreasing. Calculations showed the rate of decrease would approach the lower temperature limitation for successful vernier operation during the terminal descent phase. A 17-deg yaw, thermal corrective action was recommended to the SFOF mission operations controller, thus placing the lines in direct sunlight. This problem was remedied after the recommended action, and the spacecraft was returned to normal by simulation at $R - 1$ h.

At $R - 1$ h, voice communication with DSS 11 was lost for approximately 30 min. The SFOF mission operations controller attempted first to establish black phone communications for the command and control operations but was unsuccessful. Teletype conference circuits were established and in use by $R - 30$ min when the normal voice circuits were regained in time for the terminal descent maneuver sequence. This was a planned failure introduced by the simulation team.

Refusal of the spacecraft flight control programmer register to accept the retro delay quantity at $R - 7$ min forced the use of the DSS 11 retro sequence emergency command tape. This tape was prepared especially for this type of problem in accordance with corrective action procedures. A successful terminal descent was accomplished with the use of the tape.

The test objectives were achieved and useful experience was gained from the test series.

c. Operational readiness test. The objective of the ORT was to exercise the total space flight operations system in the mission activities preparatory to launching, and in the conduct of significant phases of the mission. Emphasis was on integrating all elements of the system and exercising as many interfaces as possible among interacting elements. This was a final dress rehearsal for the mission and was intended to verify the system's flight readiness. The test was conducted in one continuous session consisting of the following three segments:

(1) Prelaunch through initial spacecraft operations: $T - 14$ h to $T + 1$ h 45 min.

(2) Midcourse: $M - 3$ h to $M + 40$ min.

(3) Terminal: $R - 3$ h to $TD + 38$ min.

No anomalies were inserted in the system by the test conductor. All three segments were relatively uneventful. As in the flight training test, the UNIVAC 1219 computer proved to be a very valuable backup to the SFOF data system.

In general, test objectives were met.

d. Test coordination and simulation. To control and execute the A, B, and C test series in accordance with test plan objectives and directives, a joint JPL/Hughes Aircraft Co. (HAC) test coordination team was formed in July 1964. The basic responsibility of the test coordinator was to create the total test environment. The most important function of the test coordinator was to gather and specify in detail the data simulation requirements for each test and to plan for a timely and realistic display presentation to the operations personnel. To carry out these functions, the test coordination team was divided into telemetry, tracking, science, and TV simulation groups.

The prime responsibilities of the test coordinator and his staff are to: (1) plan the telemetry and tracking data packages, including problems starting about two months before the scheduled test, (2) prepare and mail data package kits, including trajectory specification, to AFETR and FR-600 telemetry simulation tapes to AFETR and Deep Space Stations for use and playback during scheduled tests, and (3) control during the test the playback of the telemetry and tracking data, which includes problems to produce a smooth-flowing realistic mission simulation.

e. Pretest simulation activities. The data packages produced in support of *Surveyor VII* were for the SPAC/flight-path analysis and command A series tests and the operational readiness test. All these packages were delivered on time and mailed to AFETR and the Deep Space Stations in time for the scheduled tests.

f. Flight training test. The *Surveyor VII* flight training tests consisted of one midcourse and one terminal run. The data packages for these tests were designed to include spacecraft telemetry problems, as well as selected ground system problems.

The problems selected and presented by the simulation test team were a mixture of spacecraft and SFOF equipment faults introduced by the test team. Typical problems presented and the portion of the mission in which they were introduced are the following:

(1) During the midcourse phase of the test, a DSS 11 time code problem was introduced by the test team starting at midcourse −45 min and continuing until midcourse completion. The problem introduced was a timing failure of the 1-pulse/s time code originating from the DSS 11 astro time code generator. Lacking the 1-pulse/s time code, the on-site data processing equipment (910 and 920 computers) could not process and ship data to the SFOF. Another result of the time code failure was that the station countdown clocks within the CDC and station mission control areas were rendered useless. The problem created procedural changes to the SFOF mission control and SPAC personnel in the handling of the midcourse command message tape normally sent via teletype to DSS 11 for processing by the on-site data processing equipment. This problem was coupled with a spacecraft flight control programmer register failure which forced the DSS 11 *Surveyor* operations chief to manually send all the midcourse commands by keyboard, based upon the timing marks for the proper maneuver durations as measured by SPAC at the SFOF. This procedure was being implemented when mission control terminated the midcourse phase. The problem of the 1-pulse/s time code simulated failure prompted an investigation of space modules and procedures to implement a fix should this problem arise during an actual mission.

(2) During the terminal descent phase, three separate nonoverlapping problems were introduced by the test team.

g. Computer program development and verification. The following IBM 7094 computer programs were designed and developed for integration into the SFOF data processing system for use in conducting *Surveyor* mission computations and operations:

(1) DPES—Direct ascent powered flight simulator (HAC).

(2) HPPS—Hughes post processor (HAC).

(3) MTGS—Midcourse and terminal guidance (HAC).

(4) ODGX—Orbit data generator (JPL).

(5) ODPX—Orbit determinator program (JPL).

(6) PRDX—JPL predicts program (JPL).

(7) TDPX—Tracking data processor (JPL).

(8) TRJX—JPL trajectory program (JPL).

Each of these programs was proven compatible in the mode 4 (7094 machine only) computer configuration before being checked out and certified in the mode 2 (7094-1301-7044) system configuration prior to the *Surveyor I* Mission. Interface of the FPAC programs via the 1301 disk file was implemented and refined during the mission simulation periods preceding the actual launches. Minor changes were made in these programs after the *Surveyor II* Mission, making it necessary to recertify the programs in the system prior to *Surveyor III*; however, no significant changes or recertifications were necessary for *Surveyor IV*. Only MTGS was recertified prior to *Surveyor V* due to minor changes in the program from *Surveyor IV*. The PRDX, TDPX, and ODPX programs were recertified prior to *Surveyor VI* due to modifications for the communications processor and the 44 redesign systems. The MTGS computer program was recertified prior to *Surveyor VII*.

V. Tracking and Data System Flight Support

A. General

The near-earth (less than 10,000 mi) phase of the *Surveyor VII* Mission was supported by the AFETR, the MSFN, the DSN, and the NASCOM. This section comprises a summary of significant events, a narrative description of countdown activities, and a presentation of actual mission performance through touchdown. The data were assembled from material presented at preflight and postflight reviews of the Tracking and Data System which supported the *Surveyor VII* Mission.

B. Countdown

The planned countdown for January 6 and 7, 1968 included two built-in holds; one of 60-min duration at $T - 90$ min, and a second 10-min hold at $T - 5$ min. Liftoff was scheduled for 05:55 GMT, on January 7, with a flight azimuth of 99 deg. The actual countdown time summary is shown in Table 13.

Table 13. *Surveyor VII* countdown time summary

Event	Time	
	Before launch, min	GMT
Started range countdown	335	23:10*
Started 60-min built-in hold	90	03:15
Hold extended 35 min for better TDS coverage	90	03:48
Started spacecraft countdown	90 (during hold)	04:20
Ended built-in hold; resumed count	90	04:50
Started 10-min built-in hold	5	06:15
Resumed count	5	06:25
Liftoff	0	06:30

*Jan 6, 1968; other times are Jan 7.

It had been decided that, during the hold at $T - 90$ min, there would be an assessment of the RIS *Twin Falls* status with reference to a minimum capability of being able to receive and record launch vehicle data. If the ship was in a GO condition in this respect, the hold at $T - 90$ min would be extended 35 min to permit liftoff on a flight azimuth of 103 deg. This would give better assurance of obtaining TDS coverage during critical periods.

The spacecraft system readiness test (SRT) was started on schedule, progressed normally, and was completed without difficulty. The first spacecraft frequency report was transmitted to the SFOF at approximately 18:30 GMT on January 6. A total of six frequency reports were sent during the SRT and countdown. The verbal reports were followed by teletype confirmation.

The first RF propagation forecast was received from AFETR at 23:00 GMT. Six of these forecasts, each of which predicted the propagation conditions for $T = 0$, were provided. In addition, the last two forecasts predicted for the conditions for launch plus 30 min. Table 14 lists the forecast conditions.

Table 14. *Surveyor VII* HF propagation forecasts

Time received, min ($T = 0$ on launch date)	Ascension/ Cape Kennedy		Pretoria/ Ascension		Sword Knot/ Pretoria		Sword Knot/ Mahe[a]		Sword Knot/ Cape Kennedy		Sword Knot/ Ascension		Twin Falls/ Cape Kennedy		Twin Falls/ Ascension		Twin Falls/ Antigua		Mahe[a]/ Ascension	
	$T = 0$	$T + 30$	$T = 0$	$T + 30$	$T = 0$	$T + 30$	$T = 0$	$T + 30$	$T = 0$	$T + 30$	$T = 0$	$T + 30$	$T = 0$	$T + 30$	$T = 0$	$T + 30$	$T = 0$	$T + 30$	$T = 0$	$T + 30$
($T = 0$: 05:55)	Fair[b]		Poor		Poor		Poor		Poor		Poor		Poor		Poor		Poor		Poor	
343																				
240																				
183																				
($T = 0$: 06:30)																				
135																				
70		Fair		Poor		Poor		Poor		Poor		Poor		Poor		Poor		Poor		Poor
30	Fair	Fair	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor

[a]Mahe: Station on island in the Indian Ocean.
[b]These values are on a scale of excellent, good, fair, (marginal), poor (mostly unusable), and unusable.

The range countdown was started on schedule at $T - 335$ min (23:10 GMT on January 6). All operations progressed normally until $T - 275$ min, when the 91.18 radar at Antigua was declared not operationally ready because of elevation encoder problems. The radar remained down until 03:28 GMT (during the built-in hold at $T - 90$ min).

At 02:54 GMT, shortly before starting the hold at $T - 90$ min, the Grand Turk 7.18 radar was also not ready, because of problems with digital formatting in the radar target acquisition system. This radar was returned to service at $T - 80$ min, at 05:00.

A weather forecast for $T - 0$ min, received at 02:25 GMT, indicated that weather conditions would be acceptable for launch.

At 02:40 GMT, the MSFN reported a problem with the peripheral antenna at Carnarvon used for determining if the main antenna was on the main lobe. A Carnarvon unified S-band problem was also reported; however, it was stated that Carnarvon was ready to support. The MSFN also stated that Tananarive support would be limited because of a continuing tunnel-diode amplifier problem.

The built-in hold at $T - 90$ min began, as scheduled, at 03:15 GMT. As anticipated, the hold was extended an additional 35 min to obtain better downrange TDS coverage.

The spacecraft countdown was started on schedule, 30 min before resuming the count at $T - 90$ min.

Telemetry data flow checks with the downrange stations and ships were successfully completed, and the real-time telemetry retransmission system was considered ready.

The built-in hold ended at 04:50; the count was resumed at $T - 90$ min.

The MSFN announced a problem with the serial decimal time equipment at Tananarive, at $T - 65$ min. This resulted in the indicated day of the year being incorrect; however, the hours, minutes, and seconds remained accurate.

No further difficulties were encountered. The built-in hold at $T - 5$ min began at 06:15 and the count was resumed as planned at 06:25. The terminal count progressed normally to liftoff.

C. Liftoff to DSIF Acquisition

The seventh *Surveyor* spacecraft was launched from launch complex 36A at Cape Kennedy, Fla., at 06:30:00:545 GMT on January 6, 1968 after a rescheduling from 05:55 to 06:30 GMT to obtain better tracking from RIS *Twin Falls*. The *Atlas/Centaur* launch vehicle launched and injected the spacecraft into lunar orbit with a launch azimuth of 102.914 deg.

The entire transit phase of the mission was nominal with all subsystems working as expected and no anomalies. At 01:05:37.6 GMT on January 9, a successful soft landing was made at 41:01 deg S and 11:41 deg W on the moon's Tycho ejecta blanket 4.2 km from the original target point, based on orbit determination data.

The spacecraft landed after a nominal terminal descent with a velocity of approximately 11 ft/s. Scheduled lunar operations, including TV surveys, antenna/solar panel positioner positioning, alpha scattering soil analysis, and soil mechanics/surface sampler (SM/SS) operation, had been successfully conducted as of 07:00 PST January 12.

Spacecraft performance during lunar operations was generally nominal. The only problem encountered was a failure of the alpha scattering instrument sensor head to deploy to the surface upon command. This problem was solved, however, by using the SM/SS to exert force on the head and thereby deploy it after tests at HAC demonstrated the feasibility of this method.

The boost phase was normal; the *Atlas* pitch program, as well as the normal opening and closing of the inertia switch, was confirmed by spacecraft telemetry. In addition, *marks* 1, 4, 6, 7, 8, and 13 (*Atlas* booster engine cutoff, nose fairing jettison, *Atlas/Centaur* separation, *Centaur* first main engine ignition, *Centaur* first main engine cutoff, and *Centaur* second first main engine ignition) were all verified in real-time from spacecraft data. Events normally detectable, that could not be verified due to data outages, were the *Atlas* roll program and *marks* 2, 5, and 15 (*Atlas* booster jettison, *Atlas* sustainer and vernier engine cutoffs, and *Centaur* second main engine cutoff). A summary of *mark* events is shown in Table 15.

Subsequent to injection and just prior to its separation from the spacecraft, the *Centaur* issued the preprogrammed commands Extend Landing Gear, Extend Omniantennas, and Transmitter High-Power-On at 07:04:37, 07:04:45, and 07:05:00, respectively. These events were not confirmed in real-time in the public address area due to a data outage, but were reported by AFETR and later confirmed in the area. Data were restored before mechanical separation of the spacecraft from the *Centaur* observed at 07:05:16 GMT.

Following separation, solar panel stepping was initiated. Also, the spacecraft cold gas jets were enabled, and the flight control subsystem nulled out the tipoff rates and initiated the roll–yaw sequence to acquire the sun. At 07:06:01, primary sun sensor lockon was observed following a roll of approximately −224 deg and a yaw of +37 deg. Concurrently with the sun acquisition sequence, the A/SPP was completing its solar panel and roll axis deployment and, at 07:14:29, the solar panel was in its proper transit position.

D. Acquisition to Midcourse Maneuver

Initial spacecraft acquisition was performed by DSS 42 (Canberra). Significant events that occurred during this phase are in Table 16. No problems were encountered during this phase and the spacecraft initial acquisition was nominal.

The spacecraft high voltage was commanded off at 07:31:47 GMT, resulting in 26 min, 47 s of high power operation during the initial acquisition phase. At 07:40:04, the 1100-bit/s data rate was selected with a resulting 27-dB nominal telemetry margin based on the reported −111.6 dBmW DSS 42-received carrier power level.

The spacecraft-received signal levels during the initial acquisition phase were −85 dBmW for receiver A and −69 dBmW for receiver B. Also, with receiver B phase locked, the difference between automatic frequency control A and static phase error B was approximately 22 kHz. It was recommended, therefore, that receiver A remain in the automatic frequency control mode since the requirement of ±25-kHz automatic frequency control for 0.0-kHz static phase error was satisfied.

During the time from initial acquisition to Canopus acquisition, the spacecraft attitude in the *X–Y* (roll) plane was uncertain to ±60 deg (i.e., the estimated uncertainty of predictions) about an estimated reference point. For the given trajectory elements of the *Surveyor VII* Mission profile, antenna gains for both the uplink and downlink signals of omnidirectional antennas A and B could be anywhere between 0 and −15 dB.

A plot of Deep Space Station received carrier power vs time was generated using the *Surveyor VII* trajectory and assuming that the spacecraft is Canopus-oriented and transmitting via omniantenna B. Actual measured mission values were plotted and coded by the Deep Space Stations. The signal level plots for spacecraft receivers A and B were also generated, again assuming Canopus acquisition.

After Canopus acquisition, the spacecraft attitude during this phase was determined by antenna contour maps of omniantenna A downlink, omniantenna B downlink, omniantenna A uplink, and omniantenna B uplink, respectively, with the earth vector trace for this mission phase and all subsequent phases superimposed. Observations of these data confirmed that operation during this phase was nominal.

Table 15. *Mark* events

Mark No.	Event	Actual time, GMT	Actual time, s	Nominal time, s
	Liftoff (2-in. motion)	06:30:00.545	L^a + 0.00	L^a + 0.0
1	*Atlas* booster engine cutoff	06:32:33.995	152.47	153.5
2	*Atlas* booster engine jettison	06:32:37.095	155.54	156.6
3	*Centaur* insulation panel jettison	06:33:18.055	197.51	198.5
4	*Centaur* nose fairing jettison	06:33:47.055	226.51	228.5
5	*Atlas* sustainer and vernier engine cutoff	06:34:09.015	248.47	248.2
6	*Atlas/Centaur* separation	06:34:11.045	250.50	250.2
7	*Centaur* main engine start 2	06:34:22.055	261.57	259.7
8	*Centaur* main engine cutoff 1	06:39:53.075	592.53	579.2
9	100-lb thrust on	06:39:54.055	593.51	579.2
10	100-lb thrust off	Not available	—	655.6
11	6-lb thrust on	06:41:10.995	670.45	655.6
12	100-lb thrust on	Not available	—	1895.32 S^b − 216.0
13	*Centaur* main engine start 2 engine C2	07:02:21.015	1940.47	1935.32 176.0
14	*Centaur* main engine start 2 engine C1	07:02:21.015	1940.47	1935.32 176.0
15	*Centaur* main engine cutoff 2	07:04:15.055	2054.51	2049.02 63.1
16	Extend landing gear	07:04:36.075	2075.53	2069.32 42.0
17	Unlock omnidirectional antenna	07:04:44.075	2083.53	2079.82 31.5
18	*Surveyor* high power transmitter on	07:05:00.005	2099.46	2100.32 11.0
19	*Centaur/Surveyor* electrical disconnect	Not available	—	2105.82 5.5
20	Spacecraft separation (injection)	07:05:16.055	2115.51	2111.32 S^b + 0.0
21	Begin *Centaur* turn around maneuver	07:05:20.005	2119.46	2116.32 5.0
22	Start *Centaur* lateral thrust	07:06:30.005	2189.55	2156.32 45.0
23	End *Centaur* lateral thrust	Not available	—	2176.32 65.0
24	Start *Centaur* tank blowdown	07:09:16.005	2355.46	2351.32 240.0
25	End *Centaur* tank blowdown	07:13:26.085	2605.54	2601.32 490.0
26	Power changeover switch	07:15:06.055	2705.51	2701.32 590.0

[a]Launch.
[b]Spacecraft separation.

Deep Space Stations 42, 51, and 61 tracked the spacecraft during this transit phase with the spacecraft transmitting data at 1100 bits/s.

During the time from star acquisition until midcourse maneuver, the spacecraft attitude was known since both the sun and Canopus had been acquired. Deep Space Stations 51, 61, 11, and 14 tracked *Surveyor VII* with the spacecraft transmitting data at 1100 bits/s in low power on omniantenna B.

Deviation from the predicted received signal level curves can be noted on both the uplink and downlink. Gyro drift checks performed during this period accounted for omniantenna gain variations that were not taken into consideration when the predictions were generated.

At approximately $T + 41$ min, 33 s, the spacecraft became visible to DSS 42 (Canberra), which achieved one-way lock. At $T + 57$ min, 54 s, the acquisition was completed when two-way lock was established between DSS 42 and the spacecraft.

The first ground-controlled sequence (initial spacecraft operations) was initiated at T + 1:01:46. Commands were sent to the spacecraft to turn off equipment required only for the launch to DSIF acquisition phase (e.g., Transmitter High Voltage and Filaments Off. Analog-to-Digital Isolation Amplifiers Off, etc.), to seat the solar panel and roll axis locking pins securely (i.e., by "rocking the axes back and forth"), to interrogate telemetry commutator modes so that the overall condition of the spacecraft could be assessed, and to change the bit rate from 550-bit/s low modulation index to 1100-bit/s normal

Table 16. Acquisition events

Event	Time, GMT (Jan 7, 1967)	Comments
Transmitter B high power on	07:05:00	Spacecraft commanded to high power by *Centaur*
DSS 42 acquires spacecraft one-way on S-band acquisition aid antenna	07:20:25	
DSS 42 automatic tracking on S-band acquisition aid/paramplifier	07:22:50	
DSS 42 switch from S-band acquisition aid to S-band Cassegrain-monopulse/maser (85-ft antenna)	07:22:57	
DSS 42 transmitter turnon	07:26:00	
Signal in passband of spacecraft receivers	07:26:07	From telemetry; receiver A in automatic frequency control capture; receiver B pulling in, not phase locked
Phase lock, receiver B	07:27:26	DSS 42 receiver dropped phase lock, indicating phase lock on receiver B
DSS 42 command modulation on	07:28:40	
Transmitter B high power off	07:31:47	Spacecraft was in high power for 26 min, 47 s for initial acquisition phase (a maximum time of 1 h is allowed)

modulation index. All spacecraft responses to commands were normal.

Because of the high value of the star intensity signal (indicating the presence of the earth in the Canopus sensor field of view), it was decided that the Cruise Mode On command should be delayed and that the flight control subsystem be kept in sun mode. Also, it was determined that there would be no need to implement the "if required" sequence for permitting receiver A to lock onto the ground transmitter signal since the signal was already well within the receiver passband (i.e., receiver A automatic frequency control telemetry indicated only a 22-kHz error).

The spacecraft continued to coast normally with its pitch–yaw axes attitude controlled to track the sun and its roll axis held inertially fixed. Tracking and telemetry data were being obtained by the use of transmitter B operating in low power in the transponder mode. The spacecraft continued to coast normally with no problems being observed. An engineering interrogation was performed beginning at $T + 4{:}06{:}14$, with the telemetry signals indicating normal spacecraft performance.

Approximately 4 h, 18 min after launch, the SFOF completed its analysis for determining the desired manner of performing the star verification and acquisition sequence. The recommendations were to obtain the star map by executing the roll maneuver with the transmitter on omniantenna B, with mode 4 data being transmitted at 4400 bits/s and with the transponder in one-way lock. It was predicted that a loss of data of up to 60 s could occur on omniantenna B, which would happen during the scan of the star Caph. A high probability of retaining the uplink signal throughout the entire sequence was predicted.

After completing an engineering interrogation initiated at $T + 07{:}36{:}31$, the spacecraft roll sequence for obtaining the star map and for locking onto Canopus was begun at $T + 07{:}54{:}04$. During the first revolution, the star intensity and error signals indicated four stars, the earth, the moon, the Milky Way, and an unidentified object. Canopus was clearly identified at 267 deg from the start of roll. The three other stars were preliminarily identified as Eta Ursa Majoris, Caph, and a combination of Gamma Ursa Minoris and Kochab. Due to the small separation between stars, the uncertainty in star intensity, a slight inaccuracy in roll rate, and the lack of high resolution on the strip chart recorder, the preliminary identification of one of the smaller stars was incorrect. The star identified as Eta Ursa Majoris was later found to be Mizar, a star about 5 deg away. One additional star, Alpha Canum Venaticorum, was found after careful analysis.

The same sources reappeared on the second revolution, except for the unidentified object which was probably a free particle. During the first passage of Canopus, the star lockon signal came on only momentarily as the star entered and left the field of view. It was therefore necessary to prepare for acquiring Canopus in the manual mode. The time of the second passage of Canopus was predicted, and sun mode was commanded at $T + 08{:}14{:}38$ to stop the roll. The maneuver stopped with Canopus very near the center of the window and, after allowing the transients to damp, manual lockon was commanded at $T + 08{:}17{:}31$, causing the spacecraft to lock onto Canopus.

Mode 5 was reselected, transponder B was turned on, the bit rate was reduced from 4400 to 1100 bits/s at $T + 08{:}19{:}58$, and the transmitter high power was commanded off 7 min, 57 s later. The vehicle returned to its coasting as before, but with its roll attitude controlled so that its star sensor remained locked to Canopus.

At approximately $T + 12$ h, the SFOF prepared the necessary data for the initial (preliminary) midcourse briefing including the plots of energy remaining in the battery, temperature matrix of all spacecraft thermal sensor values, and the up-to-date status of the key spacecraft telemetry parameters compared to their predicted values.

Continuous engineering data were obtained at 1100 bits/s for the remainder of this phase with transmitter low power. Coast mode commutator data were transmitted at all times during this phase except for the periodic interrogation of modes 4, 2, and 1 from 10 h, 31 s to 10:12:51, 11:53:12 to 12:08:39, and 14:57:18 to 15:13:06 after launch respectively. The gyro speed check took place at $T + 15{:}15{:}01$.

Two three-axis gyro drift checks from $T + 09{:}06{:}01$ to $T + 11{:}01{:}27$ and $T + 11{:}06{:}31$ to $T + 12{:}39{:}42$ were made during this phase. The solar panel switch tripped four times during transit and was commanded on again at $T + 05{:}57{:}47$, 06:16:01, 07:47:54, and 11:07:09. Spacecraft performance was flawless throughout this phase. At the conclusion of each gyro drift check, Canopus was reacquired by commanding manual lockon.

The SFOF had predicted a sun acquisition maneuver of +43 deg yaw. The actual maneuver was 225 deg roll and +43 deg yaw. No prediction was made for the roll maneuver since the *Centaur* is not roll stabilized. Canopus was acquired at 8 h, 15 min after launch with a roll maneuver of 267 deg. The roll maneuver predicted by the trajectory group was 258 deg.

The predicted view periods for the four committed tracking stations are shown in Table 17. This summary is a compilation of premidcourse and postmidcourse trajectories. The rise and set criteria are included under the Event column.

Table 17. Predicted view period summary

DSS	Event						Time, GMT
	Rise			Set			
	5-deg el	270-deg HA	90-deg HA	5-deg el	270-deg HA	90-deg HA	
51	X						Jan 7 11:28
61	X						13:08
42				X			13:26
11		X					20:58
51				X			22:14
61				X			Jan 8 01:40
42	X						04:38
11						X	09:01
51	X						12:34
61	X						13:19
42				X			14:06
11		X					21:20
51				X			22:35
61				X			Jan 9 02:13
42	X						04:58
11						X	09:16
51	X						12:47
61	X						13:22
42				X			14:14
11		X					21:26
51				X			22:40

Since the midcourse maneuver was performed on January 7 at 23:30:09 GMT, Goldstone had viewed *Surveyor VII* for about 32 min prior to the midcourse maneuver and for about 9.5 h after it. For the predicted touchdown time of 01:05:37.6 GMT on January 10, 1968, the pre- and postlanding Goldstone view periods were approximately 3.66 and 8.3 h, respectively.

The *Surveyor VII* launch phase trajectory profile is shown in Fig. 33.

Figures 34–37 show the trajectory path on the stereographic projection of DSSs 51, 11, 42, and 61. Pre- and postmidcourse injection and terminal conditions were tabulated. These results were obtained several days after the mission and are considered final. It should be noted that the postmidcourse terminal conditions did not match the orbit determination conditions very closely. This was due to use of the gas jets parameter included in the orbit determination program, which give a better fit of the data. The trajectory program could not simulate these jets.

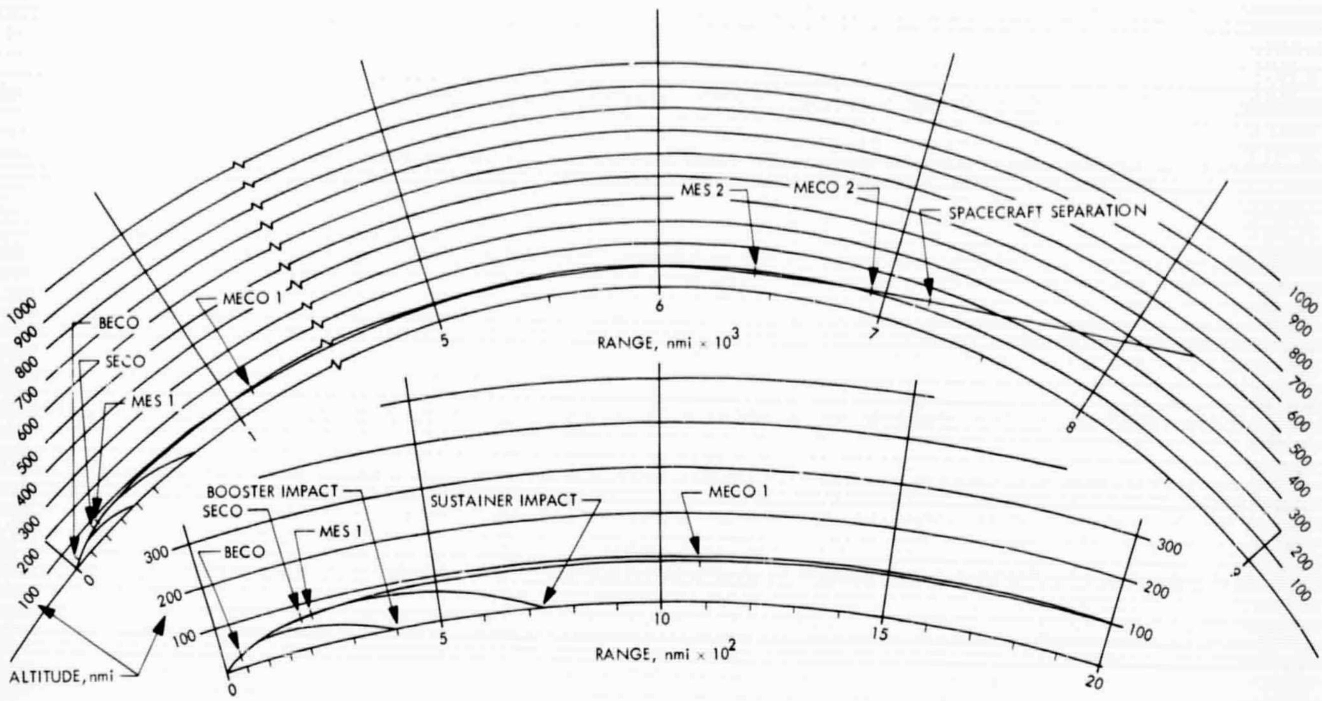


Fig. 33. *Surveyor VII* launch phase trajectory profile

The uncorrected, unbraked impact point based upon the then current best estimate was located in the central area of Hipparchus at selenographic coordinates of 6.05 deg S lat and 5.39 deg E lon. The target aiming point was 4.95 deg S lat and 3.88 deg E lon. The two points are approximately 77 km apart on the surface of the moon.

Figures of an enlarged section of the premidcourse area were provided. A few selected premidcourse orbit computations were shown. The last premidcourse orbit was used to determine the required midcourse correction. Also shown are the results of the AFETR orbit determination from the Cape Kennedy computer at 60 and 150 min after launch.

Figure 38 shows the earth track traced by *Surveyor VII*. Specific events such as sun and Canopus acquisition, midcourse maneuvers, touchdown, and rise and set times for the Deep Space Stations are also shown.

It was imperative that the computations scheduled at launch time and immediately thereafter be done on time so the latest accurate predicts could be supplied to DSSs 42 and 51 before spacecraft rise. Predictions generated at launch were lost from the buffers when both the 7044X and W computers were restarted to reestablish the communications processor interface link lost just before launch. The $T - 5$ min predictions were again generated and were transmitted successfully to DSSs 42 and 51 only a few minutes later than normal. The 7094-7044X string was subsequently replaced by the 7044Y string due to the communications processor/7044 interface problem. The card reader error problem that had occurred during the *Surveyor VI* Mission during ODPX runs appeared infrequently during this phase of the mission.

E. Midcourse Maneuver to Terminal Descent

The midcourse sequence began with an engineering interrogation at $T + 16{:}16{:}39$. All midcourse operations were performed normally. With the spacecraft controlled by DSS 11, the maneuver sequence for applying the desired midcourse thrust in the proper direction was initiated; the first maneuver (a roll of -3.1 deg) was commanded at $T + 16{:}48{:}27$. Initiation of this maneuver was delayed until the roll axis limit cycle was at a null (i.e., the Canopus error signal was passing through a null). The second maneuver (a yaw of $+117.1$ deg) was also delayed until the yaw axis limit cycle was at a null, at $T + 16{:}51{:}12$. With the vehicle thrusting direction now positioned properly, the vernier engine system was pressurized at $T + 16{:}57{:}47$. The midcourse velocity correction was applied by commanding the ignition of the

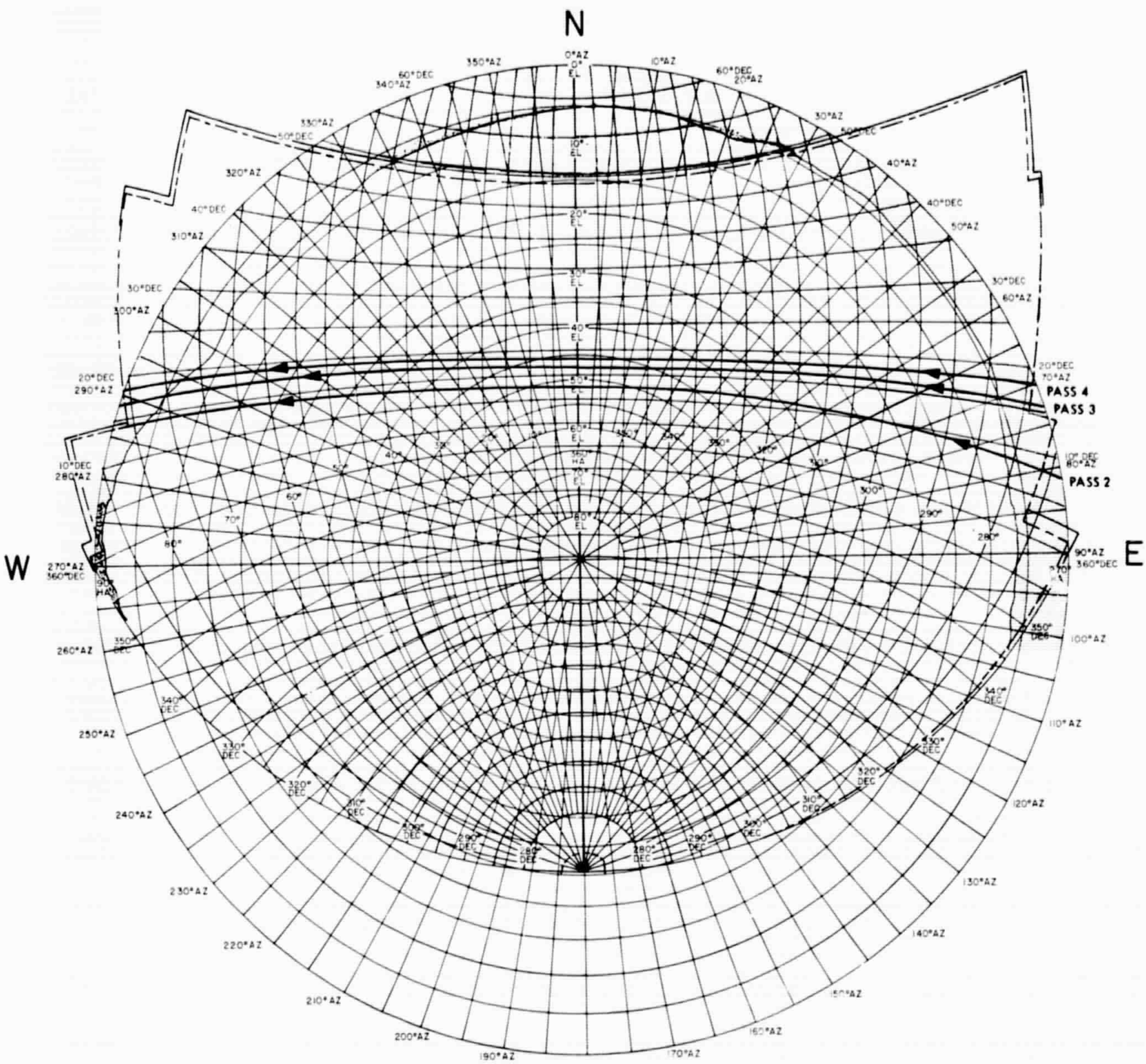


Fig. 34. Stereographic projection for DSS 51

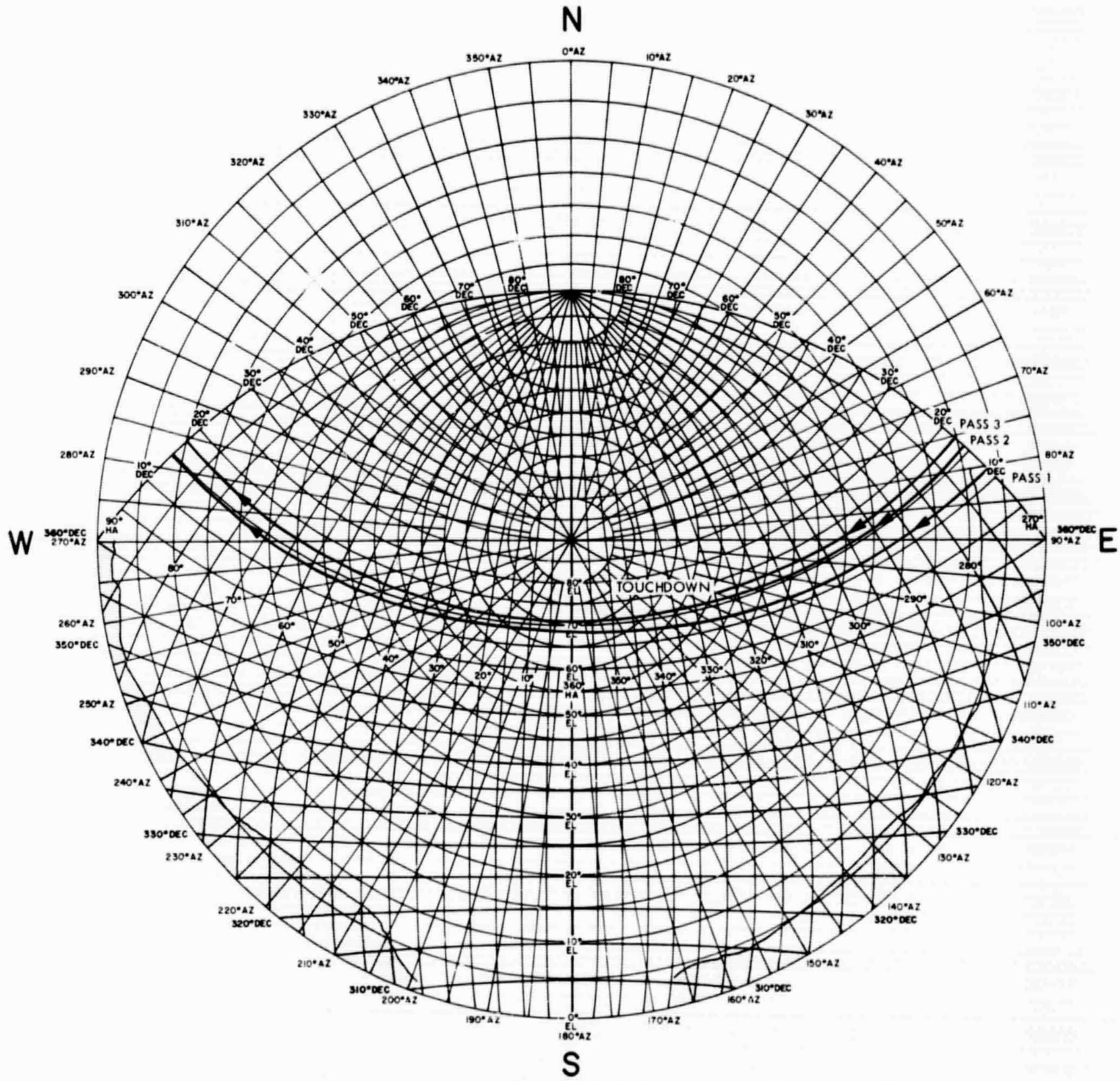


Fig. 35. Stereographic projection for DSS 11

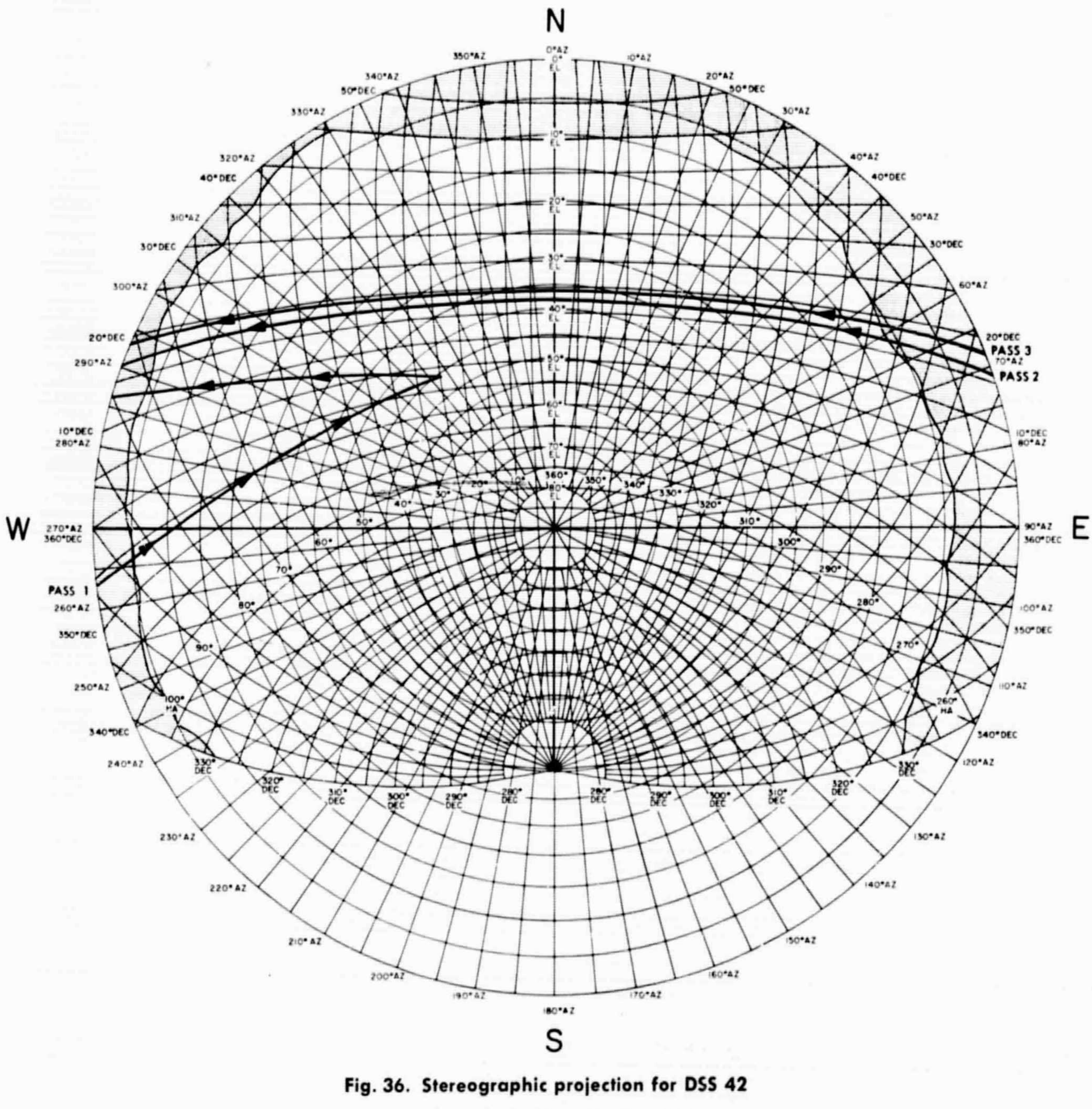


Fig. 36. Stereographic projection for DSS 42

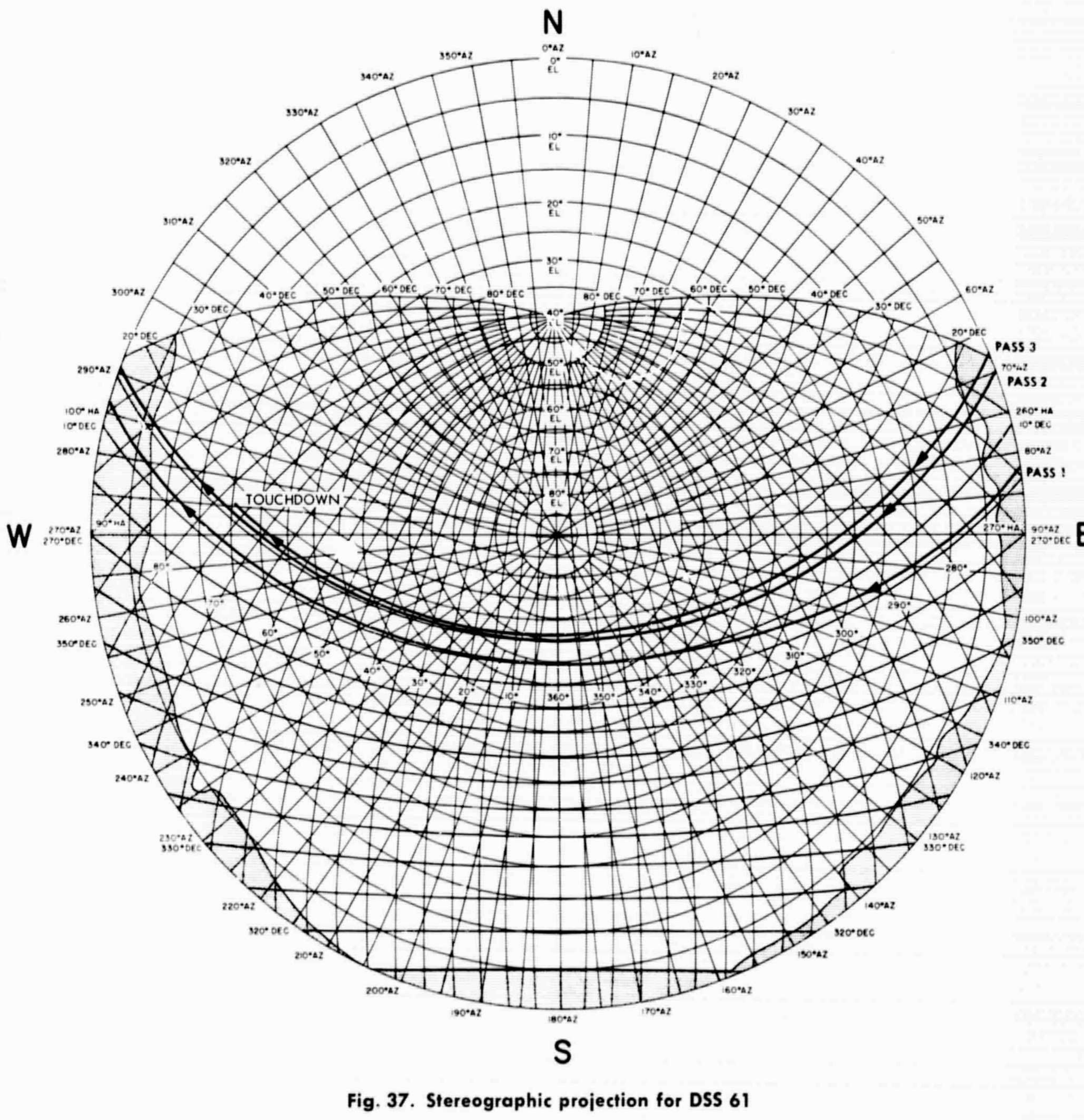


Fig. 37. Stereographic projection for DSS 61

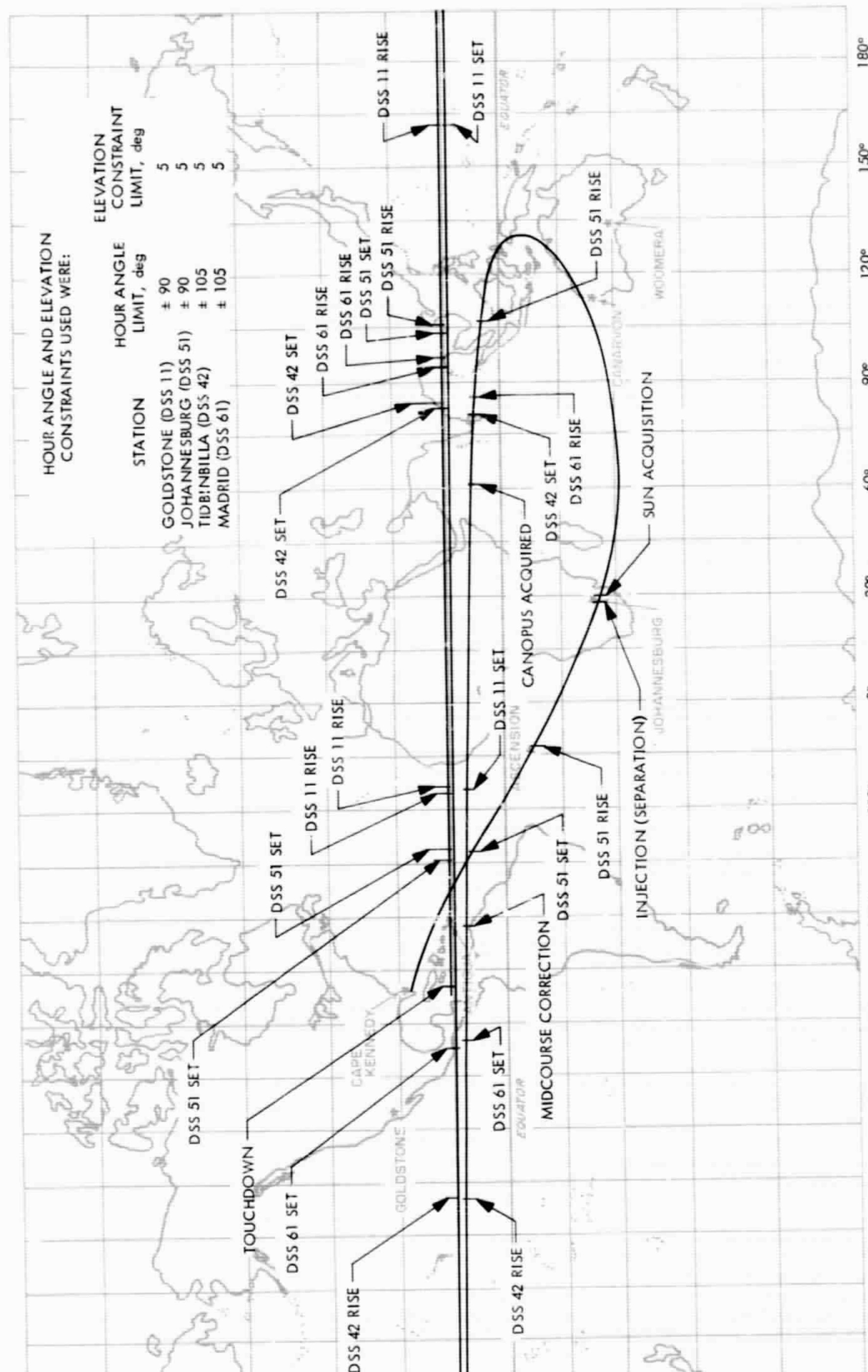


Fig. 38. Surveyor VII earth track

vernier engines at $T + 17{:}00{:}08$ so that the necessary controlled thrust was applied to achieve a constant acceleration of 0.1 g for 11.35 s (a correction of 11.13 m/s). The analog recorder, 7044 bulk and teleprinter, and 1219 teleprinter data confirmed the proper execution times and direction for the attitude maneuvers, as well as the duration of the thrusting period.

During the time from completion of the midcourse maneuver to initiation of the terminal sequence (January 8 and 9) the spacecraft operated in a low-power mode with DSSs 11, 42, 51, and 61 tracking.

At 19:55:50 GMT on January 9, the spacecraft rate was reduced to 550 bits/s. At the 1100-bit/s rate, the received carrier power at DSS 51 had been running approximately -137.0 dBmW with a nominal telemetry margin of $+1.6$ dB. Excessive errors in the data were not noted; however, the computer data system was experiencing some data processing difficulties, and the station performed an error rate check which indicated a bit error rate of approximately 0.63×10^{-3}. The bit rate reduction was then commanded, and the 550-bit/s data rate continued to be the normal data mode for the remainder of the coast phase.

Gyro drift checks were performed during this period, again accounting for deviations in signal levels from those predicted, as was the case during transit 2.

During the second tracking pass over DSS 61 (17:51:56 on January 8), the ground station antenna slewed ½ deg off the spacecraft. The result was a receiver/decoder indexing caused by receiver A. The ground station antenna servo system was switched to aided track and the antenna was moved back on point.

The earth vector to omniantenna A was in the deep null region of the antenna gain pattern for the greater part of the coast phases. During coast phase III, the signal level in receiver A was not only below the command threshold, but also varied around the receiver indexing threshold. Receiver/decoder indices occurred as a result of gyro drift checks and spacecraft limit cycling; however, no commanding problems occurred. Command activity was very low during this period and, when it was necessary to send commands, intentional indexing was initiated to ensure that receiver B was selected for command processing.

Following the midcourse thrusting, the sun and Canopus were reacquired by performing the reverse maneuvers. Thus, confirmation was obtained that the gyros had retained their inertial reference during the vernier engine shutdown, and the need to perform a postmidcourse star verification to ensure lockon to the proper star was eliminated.

The Canopus verification and acquisition analysis was performed when the preliminary computer output was received. The analysis assumed approximately a $T + 8$-h acquisition. The roll maneuver required for star mapping lies along an angle θ of 103.6 deg from the $+Z$ axis and passes through the deep null regions of both the uplink and downlink of omniantenna A and the downlink of omniantenna B. The deep null region of the omniantenna B uplink is not encountered. The following recommendations and comments resulted from the analysis:

(1) The spacecraft configuration should be high power, transmitter B, omniantenna B, 4400 bits/s, and mode 1 data. The maneuver can be executed in two-way as transponder B, if desired.

(2) There is a possibility of the loss of data between 204 and 234 deg in a positive roll sense from Canopus.

(3) Loss of the downlink carrier may also occur when passing through the null region.

(4) Only one roll on omniantenna B is required to map all stars with the exception of Caph. It is unlikely that this star could be identified even with good data, however.

At 14:18:28, transmitter B was commanded to high power with the ground-received signal level indicating an increase of 16.2 dB. The 4400-bit/s data rate was selected at 14:19:10, and transponder B was commanded off at 14:21:20. Adequate receiver B phase-lock tracking capability existed; however, one-way operation was preferred since two-way doppler data were not desired for the roll maneuver. Star mapping was initiated at 14:24:05 from DSS 61 with the spacecraft transmitting data at 4400 bits/s in telemetry mode 1.

Approximately 626 deg of roll were required to map the stars and to establish Canopus lock. Downlink signal variations of approximately 30.7 dB were noted, which agreed with the predictions for a 360-deg roll on omniantenna B. Intermittent decommutator lock occurred in the null region; however, downlink carrier lock was maintained. Manual Canopus lockon was successfully commanded at 14:47:32. Uplink signal level variations for the null maneuver were 31.3 dB for receiver A and 27.2 dB for receiver B as opposed to predicted variations of 27.2 and 25.4 dB for receivers A and B, respectively.

Variations in antenna gain were seen in the data when compared to predicted variations for both the downlink and uplink. The correlation between the two sets of data is typical of that observed on previous spacecraft for both the uplink and downlink of omniantenna B. Lower gain values than predicted are indicated between the $-Y$ and $-X$ axes on the omniantenna A uplink. This had been observed on previous spacecraft; however, a null was also observed in the predicted high gain region which starts at the $+Y$ axis and extends for 40 deg in the direction of the $+X$ axis.

Transponder B was turned on at 14:51:04 and two-way operation was reestablished. The spacecraft was commanded to 1100 bit/s data at 14:56:48. Transmitter B high power was commanded off at 14:57:56, which resulted in 38 min 20 s of high power operation for star acquisition. The DSS 61 received carrier level for low power operation was -127.3 dBmW, which was a 16.2-dB decrease from high power and resulted in a 11.3-dB nominal telemetry margin for 1100-bit/s data.

The postmidcourse coast phase was begun and continued until initiation of the terminal-descent maneuvers. Throughout this period, data were transmitted continuously at 1100 or 550 bits/s by the low-power transmitter. During this interval, six additional three-axis gyro drift checks were made at $T+$:

(1) 17:34:11 to 30:12:57.

(2) 23:36:22 to 26:05:49.

(3) 31:32:21 to 34:44:32.

(4) 44:35:44 to 47:04:23.

(5) 48:46:23 to 51:18:31.

(6) 20:18:54 to 23:32:41.

Thirteen interrogations of modes 4, 2, and 1 were made during this interval at $T +$:

(1) 19:01:55.	(8) 47:41:35.
(2) 24:18:45.	(9) 25:29:40.
(3) 29:22:03.	(10) 55:44:00.
(4) 33:30:36.	(11) 59:36:50.
(5) 36:39:41.	(12) 62:28:08.
(6) 39:25:27.	(13) 64:17:49.
(7) 42:49:28.	

Other sequences which were accomplished included: (1) Turnon of vernier oxidizer tank 2 thermal control at $T + 32:34:57$. (2) Compartment A thermal control turned on at $T + 55:30:20$ and off at $T + 63:34:13$. (3) Survey TV electronics thermal control turned on at $T + 59:49:45$. (4) Bit rate reduction from 1100 to 550 bits/s at $T + 61:25:15$. (5) Compartment C thermal control turned on at $T + 63:57:23$. (6) Turnon of the alpha scattering instrument heater at $T + 64:01:59$. (7) Compartment A heater turned off at $T + 64:14:03$. (8) Vidicon temperature control turned on at $T + 65:23:47$. A gyro speed check was performed at $T + 64:29:16$ and 50 normal readings were obtained on all three gyros. The narrowband, voltage-controlled crystal oscillator frequency was checked 5 min, 11 s later to permit determination of the frequency offset required for terminal descent.

At $T + 62$ h, 45 min, the retroengine bulk temperature was computed to be 54°F, and a temperature of 53°F at retroignition was predicted. It was estimated that the resulting retromotor burn time would be 42.78 s. This information was furnished to flight-path analysis and command group at the final meeting with SPAC at $T + 62$ h, 45 min, in addition to the following data: (1) the pitch gyro draft rate was 40.2 deg/h, (2) the yaw gyro drift rate 0.0 deg/h, and (3) the roll gyro drift rate, -0.65 deg/h. It was also agreed that an attempt would be made to control the initiation time of the first two maneuvers so that the limit cycle errors would be minimized (i.e., similar to the procedure used in executing the premidcourse maneuvers).

Preliminary analysis of the midcourse maneuvers was performed at the SFOF upon receipt of the flight-path analysis and command group output. Eight maneuver combinations were analyzed for a $T + 16$-h midcourse maneuver. The maneuver analysis summary form was tabularized. Detailed analysis of other outputs were not performed since variations were less than 4 deg from the corresponding preliminary maneuvers. Variations of 4 deg in omnidirectional antenna gain patterns will not affect performance margin calculations beyond the inherent uncertainty of the preliminary analysis. The roll-yaw standard maneuver was selected with the spacecraft configuration as follows:

(1) Transmitter B/omnidirectional antenna B/high power.

(2) 4400-bit/s data.

(3) Two-way lock.

At 23:02:03 GMT, the spacecraft was commanded to high power and, at 23:20:41, the 4400-bit/s data rate was selected. The ground-received signal increased by 15.6 dB when the spacecraft was commanded from low to high power, with DSS 11 reporting a received carrier power of −120.3 dBmW prior to maneuvering. Maneuver initiation times were 23:18:28 for the roll and 23:21:13 for the yaw. Illustrated earth vector traces were made of the maneuver on each of the applicable antenna pattern contour maps. Signal level variations during the maneuver are shown in Table 18. The DSS 11-received carrier power of −121.0 dBmW at the end of the premidcourse maneuver indicated that a nominal 19.0-dB telemetry margin existed for 4400 bit/s data.

Table 18. Signal level variations during midcourse maneuver

Attitude, rotation deg	Signal level variations, dB					
	Spacecraft to earth (omnidirectional antenna B)		Earth to spacecraft			
			Receiver A		Receiver B	
	Predicted	Observed	Predicted	Observed	Predicted	Observed
Roll −3.2	1.1	0.1	6.8	4.2	0.5	6.1
Yaw +117.0	2.4	2.4	5.6	30.4	1.8	2.3
Thrust	—	0.1	—	1.7	—	0.6

Midcourse thrust was executed at 23:30:09 GMT. Carrier power received from DSS 11 was steady, with reported 0.1 dB variation during the thrusting period.

At 23:31:39 GMT, mode 5 data were selected in preparation for the postmidcourse maneuver. The yaw initiation time was 23:34:11. The reverse roll maneuver was not necessary since Canopus was in the sensor field of view at the end of the reverse yaw. The uplink and downlink signal levels during the postmidcourse maneuver essentially retraced those seen during the premidcourse maneuver.

Manual Canopus lockon was commanded at 23:41:08, and preparations were made to return the spacecraft to its cruise configuration. At the end of the midcourse sequence, the DSS 11 received carrier power of −120.3 dBmW indicated that a positive nominal 1100-bit/s telemetry margin should exist with the spacecraft in the low power mode. At 23:49:00, the 1100-bit/s data rate was selected, and at 23:51:19 transmitter B high voltage was commanded off. The spacecraft operated in high power for 49 min, 16 s during the midcourse maneuver sequence. A decrease of approximately 16.3 dB from high to low power was noted. The resulting −132.0 dBmW received carrier power produced a +6.6 dB nominal telemetry margin for 1100-bit/s data.

Analysis was also performed on 16 maneuver combinations for a second midcourse maneuver which would be performed during the second tracking pass of DSS 11. The roll–yaw optional maneuvers of either the $+U_3$ or $-U_3$ velocity components were selected as the preferred maneuvers, with the recommended spacecraft configuration being identical to that for the first midcourse maneuver. It was subsequently determined, however, that it would not be necessary to perform a second midcourse correction.

F. Terminal Descent to Touchdown

Terminal descent was initiated at $T + 65{:}29{:}10$ with the performance of the last engineering interrogation. The terminal-descent attitude maneuvers were initiated 35 min, 2 s prior to the predicted time of retroignition ($T + 65{:}57{:}13$). In accordance with the prior agreement, the first maneuver (a roll of 80.5 deg) was initiated as the Canopus error passed through its null position. Similarly, initiation of the second maneuver (a yaw of +96.1 deg) was delayed until $T + 66{:}05{:}49$ when the sun sensor yaw error was crossing its null position. These first two maneuvers (which aligned the retroengine thrust axis to the desired direction) were completed at $T + 66{:}09{:}04$. A third maneuver (a roll of −16.5 deg) established the preferred spacecraft orientation at retroignition and at touchdown to reduce the probability of the RADVS breaking lock and to provide the desired postlanding visibility of engine 3 by the TV camera, was initiated at $T + 66{:}11{:}06$ and completed 33 s later.

The three maneuvers, as well as other pre-retroignition spacecraft operations (e.g., loading the proper altitude *mark*-to-vernier-ignition delay quantity—2.775 s, establishing the retroignition sequence mode to ensure that the automatic flight control sequences would occur in response to the altitude radar mark, establishing the proper vernier engine thrust level for the retroignition phase, and turning on flight control thrust phase power, etc.), were executed on schedule and without difficulty. In addition, the altitude marking radar (AMR) was turned on at $T + 66{:}27{:}33$ and enabled 3 min later.

Prior to the terminal maneuver sequence, three operational inputs were required from the telecommunication subsystem. These inputs were:

(1) Terminal maneuver telecommunication performance analysis.

(2) Deep Space Station transmitter frequency offset prior to retromotor firing.

(3) Touchdown strain gage feasibility analysis and turnon criterion.

Preliminary analysis of the terminal maneuver was performed on those maneuvers based on the final midcourse computation. Again, as in the case of the midcourse maneuver analysis, detailed analysis of subsequent terminal maneuver computations was not performed since variations in the corresponding maneuvers were less than 2 deg. The maneuver analysis summary form presenting the results of the eight maneuver combinations were analyzed closely. The roll–yaw–roll standard maneuver was selected with the spacecraft configurations as follows:

(1) Transmitter B/omnidirectional antenna B/high power.

(2) 1100 bits/s data.

(3) One-way lock.

The spacecraft velocity change from retroignition to touchdown caused the effective spacecraft received frequency value to increase. It is important to maintain command capability with the spacecraft; therefore, the Deep Space Station transmitter frequency was adjusted prior to retroignition to a value that enabled the spacecraft-received frequency, both before and after ignition, to have minimum deviation from the automatic frequency control center frequency of the receiver selected to be optimized. To complicate the determination of the frequency offset value, the frequency adjustment is made when the spacecraft is operating in the transponder mode. It was necessary then to determine what static phase error frequency corresponded to the desired automatic frequency control frequency. This was determined for receiver B at 23:04:26 GMT (January 9) when transponder B was turned off to perform the narrowband voltage-controlled crystal oscillator check. The touchdown frequency offset summary was tabulated. At approximately 23:52:00, the DSS 11 transmitter frequency was set so that static phase error B read -1.8 kHz. The doppler change from transmitter tuning to the time when transponder B was turned off (00:21:51 GMT, January 10) caused static phase error B to read -4.7 kHz and the corresponding automatic frequency control B after turnoff to read 0.3 kHz. At touchdown, automatic frequency control B read 8.4 kHz, which was in complete agreement with the desired value of 8.25 kHz.

Following the terminal maneuver evaluation, the touchdown strain gage feasibility analysis was performed and a turnon criterion established. Best estimates of spacecraft worst-case performance during descent and at touchdown indicated that, with the strain gage activated, 1100-bit/s data could be obtained at a 3×10^{-3} bit error rate at either DSS 11 or DSS 14 with the spacecraft transmitting on omniantenna B. It was recommended that the strain gages be turned on if the received carrier power at DSS 14 was greater than -127.6 dBmW at the end of the terminal maneuver with the spacecraft transmitting data at 1100 bits/s only.

For the greater part of the coast phase, the earth vector to omniantenna A was in the deep null region of the antenna gain pattern. At the time of preparation for the terminal sequence, spacecraft limit cycling caused the signal level in receiver A to vary through the indexing threshold. At all times the signal was well below command threshold for this receiver. During commanding it was necessary to assure that receiver B was related for command processing. However, receiver indexing at times occurred so frequently that it was necessary to repeat some commands. Commands to select the coast-phase commutator, to turn on high power, and to turn off transponder B had to be repeated. The indexing would not be a problem during descent since the earth vector to omniantenna A would leave the null region after the spacecraft had rolled approximately 5 deg.

The spacecraft was commanded to high power at 00:07:23 GMT (January 10), and 1100-bit/s data were selected at 00:12:32. The resulting -123.3 dBmW signal level indicated an increase of 15.9 dB over low power operation. Transponder B was turned off at 00:21:51, establishing the spacecraft configuration for the terminal sequence. Maneuver initiation times were 00:27:14 for the first roll, 00:35:50 for the yaw, and 00:41:07 for the second roll.

The DSS 11-received carrier power at the completion of the second roll maneuver was -125.9 dBmW, which was in agreement with the nominal 1100 bits/s on transmitter A. Omniantenna A was selected at 01:30:41, with a resulting 2.1-dB decrease in the ground-received signal.

Omniantenna B was reselected at 01:31:24 because it was the favorable transmitting antenna. The ground-received total power of −121.1 dBmW resulted in a 10.3-dB nominal margin for 200-line TV pictures. The spacecraft was configured for 200-line TV by approximately 01:41:00, with the first picture being obtained at approximately 01:47:00.

Starting at touchdown, minor fluctuations in the received signal levels of both the uplink and downlink were noted. A check of associated subsystem elements indicated that the spacecraft was performing as expected. This condition then implied that a possible RF multipath situation existed; however, normal spacecraft operation was not affected by the resulting signal level variations.

The automatic-descent sequence was initiated by the altitude marking radar *mark*, generation of the *mark* was confirmed on the ground at 01:02:11.930 GMT (T + 66:32:11). Vernier engine ignitions, retroengine ignition, RADVS initial turnon and application of high power after 18 s, retroengine burnout, and retroengine separation occurred normally. The moment disturbance produced by the retroengine firing was small (on the same order as the previous spacecraft) and indicated that there was no large center of gravity offset. When the enable doppler control signal was generated (2.15 s after retroengine separation was initiated), the doppler control phase was initiated. Realignment of the spacecraft Z axis to the existing velocity vector was accomplished in 3–4 s, with the gyro error signals confirming that the spacecraft was being controlled normally during this phase.

The vernier engines, under control of the RADVS, kept the spacecraft on the desired range-V_z contour, and the 1000-ft, 10-ft/s, and 14-ft *marks* were generated as expected (telemetry confirmation was received on the ground at T + 66:34:28, 66:35:30, and 66:35:36, respectively). Touchdown occurred at T + 66:35:37.075, with continuous data being received and the spacecraft in excellent condition. Postlanding shutdown sequences were immediately initiated with an engineering assessment performed and the spacecraft prepared for television operations. Table 19 shows the *Surveyor VII* terminal descent sequence of events.

G. Touchdown to End of Mission

Terminal descent was nominal with all events occurring as expected. Touchdown was at approximately 13 ft/s, the order of leg contact was 1, 3, and 2 on a slope of approximately 3 deg, as estimated from gyro error signal shifts at touchdown and relative timing of the leg impacts.

Table 19. *Surveyor VII* terminal descent sequence

Event	Time, GMT	
	Actual	Predicted
AMR 60-mi *mark*	02:11.930	02:11.944
Vernier ignition	02:14.730	02:14.744
Retroignition	02:15.830	02:15.844
Retroburnout	02:59.028	02:59.043
Retroeject	03:11.028	03:11.042
RADVS control descent	02:13.128	02:13.142
1000-ft *mark*	05:13.323	05:13.338
10-ft/s *mark*	05:30.223	05:30.237
14-ft *mark*	05:36.322	05:36.337

All spacecraft systems operated extremely well during the transit and lunar phases, spacecraft thermal performance was excellent and all temperatures were essentially nominal. Thermal performance during lunar operations indicated a lunar surface temperature some 20°F higher than expected.

The telecommunications system performed essentially nominally as expected during the transit part of the mission. Operation during the lunar phase was generally nominal; however, on three occasions lunar reflections interfered with uplink commanding.

Electrical power system performance during transit was normal. The battery was fully charged at launch and the voltage remained high, resulting in tripping of the solar panel switch only three times during the transit phase.

Lunar performance operations were generally as expected. Postlanding operations prior to the first 200-line TV picture were also normal as expected. Attitude determination, using combined A/SPP fine positioning data and gyro error signal shifts at touchdown, was completed at 12:38 GMT on January 10.

By January 26, more than 20,000 TV frames had been obtained. These included narrow-angle and wide-angle surveys of the lunar surface and pictures of earth and Jupiter.

In summary, the *Surveyor VII* Mission was regarded as a very successful mission in terms of: (1) overall spacecraft performance, (2) accuracy achieved by the midcourse correction making a second correction unnecessary, and (3) successful operation of all scientific payload instruments, including use of the soil mechanics/surface sampler (SM/SS) to deploy the alpha scattering instrument (ASI) sensor head.

The overall support effort for the *Surveyor VII* Mission, as well as for previous missions, was significantly enhanced through the availability and use of the Spacecraft Checkout Computer Facility 1219 computer data system. The loss of prime (7044 system) data during the critical final minutes prior to this launch, extending through liftoff, has demonstrated the real need and usefulness of the Spacecraft Checkout Computer Facility backup system.

In addition to being highly reliable, the computer facility has demonstrated complete compatibility with the prime 7044 system. From the user standpoint, it was recognized that the two computer systems were complementary, not competitive, in that the computer facility was programmed to display any change in an unlimited number of signals, whereas the 7044 was programmed to display all samples of a limited number of selectable parameters.

It was recommended that the Spacecraft Checkout Computer Facility be made an integral part of the DSN/SFOF computer data processing configuration.

The aiming point at the time of the midcourse maneuver was 40.870 deg S lat and 11.37 deg W lon. Based on the final postlanding orbit determination, the computed landing site of *Surveyor VII* was determined to be at 41.059 deg S lat and 11.451 deg W lon. This resulted in a 6.0 km miss from the predicted aiming point.

In addition, a study of *Lunar Orbiter* photographs of that area revealed the probable landing site to be 40.89 deg S lat and 11.44 deg W lon. From this determination, a miss of 1.69 km was indicated.

Surveyor VII touched down south of the equator, with its $-Y$ axis 22 deg west of north; this orientation resulted in the scientific payload being illuminated for most of the lunar day. Figure 39 shows the *Surveyor VII* landing location.

A number of backup command execution times were computed for the *Surveyor VII* Mission. These included the following:

(1) The optimum time to transmit the backup AMR *mark* command. The strategy employed to generate this command was based upon a predicted probability of 0.999 that the marking radar would work.

(2) The time to transmit the emergency AMR *mark* command given that the marking radar was known to be inoperative. The command could have been sent at this time if confirmation of AMR Power On and AMR Enable were not received.

(3) The time to start the emergency terminal-descent command tape. This tape could have been used if the counter were known to be inoperative and would have started with the vernier ignition command.

The computation of these command times was based on the final estimate of the unbraked impact time and the uncertainty associated with it. These values were obtained from the final pre-retromaneuver orbit determination generated 40 min prior to ignition. The uncertainty (orbit determination and manual implementation) associated with executing the AMR backup command was determined to be $[(0.70)^2 + (0.15)^2]^{1/2} = 0.715$ s ($1\,\sigma$). Using this value and the amount of predicted vernier engine propellant available, a backup delay of 1.2 s was specified. Known fixed delays such as the propagation delay, operator delay, command generator, and command decoder delays totaled 2.37 s. Fixed delays were anticipated by executing the command early. In addition, because of a questionable situation with regard to determining the final unbraked impact time via orbit determination, a conservative bias of 1 s was added to the backup transmission time. The final time for transmission of the AMR backup command, rounded up to the next second, was 01:02:12 GMT. This backup *mark* command should have arrived at the spacecraft approximately 3.1 s after the predicted *mark*. The predicted and estimated AMR *mark* and backup times (GMT) were as follows:

Mark	Backup
01:02:11.28 (predicted)	01:02:14.37 (predicted)
01:02:10.60 $\pm$0.05 s (estimated)	01:02:14.52 $\pm$0.1 s (estimated)

For commands (2) and (3), the approach taken was to determine a new burnout altitude centered with respect to the total burnout capability defined by the midcourse maneuver, descent contour, and predicted nominal burnout velocity. In general, the new burnout altitude is greater than the nominal value, and this higher burnout altitude gives rise to earlier desired backup *mark* and

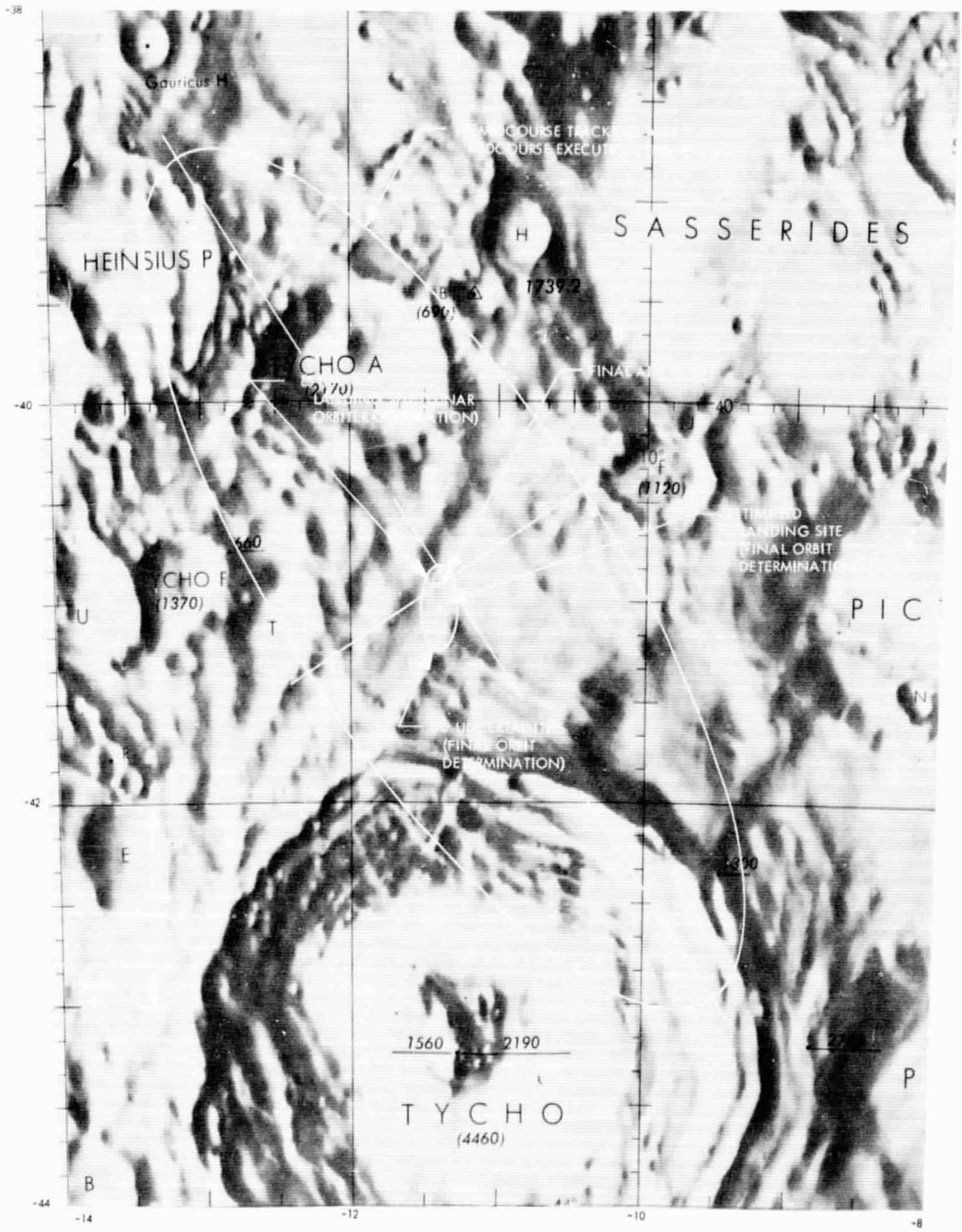


Fig. 39. *Surveyor VII* landing location

ignition command times. These backup command times (GMT) for the *Surveyor VII* Mission were as follows:

Command	Time
Emergency *mark*	01:02:08
Start terminal-descent command tape	01:02:12

1. Downlink signal variation. Shortly after touchdown, after the 200-line TV pictures were taken, the downlink signal varied in magnitude (about 0.7–1.0 dB) and frequency for several minutes. It was suspected at the time that these variations may have been caused by multipath transmission effects, and a special telecommunications test was designed by SPAC to define the cause. This special test was performed on day 016 between 15:49 and 18:31 GMT from DSS 42 and again between 14:03 and 15:03 GMT on day 017 from DSS 11.

2. Alpha scattering head deployment problem. The alpha scattering head was deployed to the background position at 15:48 GMT on day 010 and calibrated. At approximately 22:01 GMT the command to deploy the head to the lunar surface was transmitted. Television pictures taken after the deploy command indicated that the head was still suspended. However, all deployment functions up to the sequence where the escape mechanism is supposed to lower the head to the surface functioned properly. Attempts to shake the head loose by stepping the SM/SS were not successful. Initial attempts to shake the head loose with the SM/SS were also unsuccessful. Deployment procedures were then developed on a crash basis and extensively tested. Operations to implement these procedures were initiated at approximately 07:30 GMT on day 012. The first problem was that the head was too high to position the SM/SS claw on top for the purpose of pushing down. Because of this situation the claw was opened and positioned on the skirt that projects around the bottom of the head. The head was nudged against the side of the spacecraft by the claw and then forced downward with considerable force. As a result, the head was moved down sufficiently to position the claw on top. The head was then lowered with a series of short pushes until it was finally confirmed that it was in contact with the lunar surface.

3. Television command failures. On day 014 at 15:48 GMT and again at 07:15 GMT on day 015, the TV camera failed to respond to some commands. Subsequent investigation indicated that: (1) The same TV command tape was utilized by DSS 42 and DSS 11, with the spacecraft not responding to the same TV commands at the identically same point on each command tape. (2) The television electronics temperature was near its upper operational limit at these times. (3) All commands were confirmed as being transmitted.

Thermal analysis using data from *Surveyors III*, *V*, and *VI*, together with the projected cooler environment, predicted that units of the scientific payload would not exceed their survival limits during the day. However, the SM/SS electronics auxiliary, the alpha scattering sensor head (ASSH), and compartment C were expected to exceed their upper operational temperature limits of 158, 122, and 131°F, respectively.

Following the touchdown of *Surveyor VII*, subsystems of the scientific payload were above their maximum operational temperature limits longer than payloads associated with previous spacecraft; hence, the available time for scientific exploration was less for the *Surveyor VII* lunar mission. During previous missions, the solar panel and planar array were often used to shield units and subsystems from direct solar illumination, thereby increasing the unit operational time. However, because of the touchdown site and spacecraft orientation, it was not possible to use the planar array and solar panel to cast shadows over the scientific payload during the mid-morning to mid-afternoon interval.

4. Alpha scattering experiments. Preflight predictions indicated that the ASSH would exceed its upper operational temperature limit of 122°F at a solar azimuthal angle of 95 deg (or 45 deg from the solar azimuth corresponding to zero degree elevation). The ASSH exceeded the upper temperature limit at a solar azimuthal angle of approximately 93 deg. However, contrary to predictions, the ASSH also exceeded its survival temperature limit of 158°F. The ASSH reached a peak temperature of 163°F. Preliminary thermal analyses indicated that the higher than expected temperatures were probably caused by one of the following or both:

(1) Uncertainties in the optical properties, especially the solar absorptance, associated with the ASSH vycor mirror, and in the thermal contribution of the sides of the container to radiator and electronics temperatures.

(2) Uncertainties in the thermal contribution caused by infrared energy exchange with the lunar surface and the reflected component of insolation from the spacecraft.

The ASSH radiator (vycor mirror) optical properties are measured prior to subjecting the spacecraft to systems level solar thermal vacuum tests; property measurement data indicate that the optical properties are nominal, i.e., $\alpha \sim 0.11 \pm 0.02$ and $\epsilon \sim 0.80 \pm 0.02$. In general, if contamination prior to launch is eliminated, it becomes plausible that the thermal coupling between the ASSH electronics/radiator assembly and the ASSH shielding compartment is probably an order of magnitude greater than predicted.

5. Alpha scattering electronics compartment. The alpha scattering electronics compartment (ASEC) like the ASSH exceeded its upper operational temperature limit of 131°F. The ASEC reached a peak temperature of 157°F during the first lunar day. The orientation of the ASEC thermal radiator results in peak solar heating at sun elevation angles of 45 ±5 deg for equatorial landings (approximately 20 h). However, the ASEC thermal radiator is subjected to peak or near peak solar loads for several days at the Tycho latitude. The increased period of near peak solar heating coupled with the infrared energy exchange with the lunar surface resulted in the ASEC being above its upper operational temperature limit longer than on previous missions.

6. Soil mechanics/surface sampler subsystem experiment. The SM/SS subsystem has two major units: a surface sampler mechanism and an auxiliary electronics compartment. The lunar day thermal performance of the *Surveyor VII* auxiliary compartment indicates that the compartment experienced either/or both a "hotter" thermal environment and higher solar energy heating load than previous *Surveyor* spacecraft.

The spacecraft touchdown orientation and Tycho location resulted in the maximum period of direct illumination in the landing leg 2 region of the spacecraft. The SM/SS auxiliary electronics compartment and the mechanism which are located in this region were insulated throughout most of the lunar day.

The maximum temperature of the SM/SS compartment (180°F) was 40°F higher than that experienced on *Surveyor III* (the previous successful spacecraft with an SM/SS subsystem). The maximum operating temperature of 158°F was exceeded for a period of 95 h. An extrapolation of *Surveyor III* thermal data for the period when the compartment was shaded indicates that a maximum temperature of 155°F could have been attained. Therefore the maximum temperature of the *Surveyor VII* auxiliary electronics compartment was 25°F warmer than the extrapolated peak for that of *Surveyor III*.

There were no flight sensors on the *Surveyor III* SM/SS motors; therefore, no comparison may be made of the *Surveyors III* and *VII* thermal performance. However, the bulk temperature of the mechanism had been analytically predicted as a function of percentage illumination. A maximum bulk temperature of 196°F was predicted for 50% illumination. This compares closely to actual maximum temperatures of 186 and 196°F, respectively, for the *Surveyor VII* elevation and retraction motors.

7. Survey TV camera. Operation of the survey television camera was limited during the mid-morning to mid-afternoon interval as a result of high temperatures. Preflight thermal analyses indicated that the survey TV camera would be operation-limited at the southerly latitude. Thermal predictions indicated that the electrical conversion unit could exhibit temperature rise rates of 1.1°F/min. The actual electrical conversion unit temperature rise rate is a function of the camera duty cycle and actual internal power dissipation (which is dependent on available battery voltage). The *Surveyor VII* electrical conversion unit exhibited an average temperature rise of 1.0°F/min during one operational interval of approximately 7 min. The upper operational temperature limit for the survey camera electrical conversion unit is 165°F.

8. Television performance. The first 200-line TV picture was transmitted approximately 40 min after touchdown. Based on reported DSS 11 signal levels, the computed nominal signal-to-noise ratio for the first picture was 14.8 ±1 dB.

The first 600-line TV picture was transmitted approximately 2½ h after touchdown, shortly after the planar array was roughly aligned with the earth. Based on reported station signal levels, the computed nominal signal-to-noise ratio for the first picture was 16.3 ±1.0 dB.

In both cases, the signal-to-noise ratio was high enough to provide good quality detected video data which is apparent in the quality and resolution of the pictures.

Transmitter A was used for 600-line TV operations until day 014, at which time the center frequency of the wideband voltage controlled crystal oscillator drifted outside the tuning range of the DSS 11 receivers. The upper tuning limit of the DSS 11 receivers is 2295.234560

MHz, and at 22:00 GMT on day 014 the measured center frequency of spacecraft transmitter A operating in the wideband FM mode was 2295.236480 MHz. Transmitter B was activated and used until day 021, at which time the frequency of the wideband voltage controlled crystal oscillator of transmitter A was again within ground station limits. Transmitter A was then selected and used for the remainder of the lunar day. Trouble/failure report 18273 was generated against transmitter A based on the above experience.

When the oscillator center frequency drifted 245 kHz above the nominal 2295 MHz value during ground tests trouble/failure report 87206 was written against this same transmitter on October 2, 1967. This report was closed without corrective action on the assumption the frequency was within the handling capability of the station ground equipment. This frequency was, in fact, beyond the tuning range of the receiver voltage controlled oscillator available on site at DSS 11.

9. Alpha scattering performance. The alpha scattering experiment was performed during much of the first lunar day. The total power at the ground station with the planar array pointed toward the earth was reported to be approximately −110 dBmW. This signal level for the 7.35 kHz PCM subcarrier oscillator/alpha scattering multiplex mode resulted in nominal signal-to-noise ratios of 25.0 dB for the 7.35 kHz PCM channel, and 21.9 and 20.1 dB for the two alpha scattering channels. Good quality data, therefore, were expected and received for this experiment.

10. RF and signal processing tests. During *Surveyor VI* lunar operations, tests were conducted to provide data for evaluation of the performance of the spacecraft telecommunications RF and signal processing systems. The RF communications test is identified in the SPAC performance analysis detailed operating procedure as optional sequence 16 and the signal processing test as optional sequence 17 (Table 20). Based on real-time observations and preliminary posttest analysis, the RF and signal processing subsystem performances during all tests were as expected.

11. Signal level variations during lunar operations. Throughout the lunar day, periodic fluctuations were observed in the telemetered automatic gain control of both spacecraft receivers and in the ground station received signal level when the spacecraft transmitter was radiating on an omnidirectional antenna. No downlink fluctuations were evident when transmitting via the planar array antenna. This phenomenon was first noted immediately after touchdown. Relatively large step changes in the spacecraft receiver automatic gain control were noted at station transfers.

12. First lunar day operations. The postlanding power shutdown was commanded immediately after touchdown and the postlanding engineering assessment was shortened in order to initiate 200-line TV operations as quickly as possible. The first picture was commanded at 01:46:50 GMT. In this mode, a total of fourteen 200-line frames were commanded and received, all of good quality, and the camera was commanded off at 02:11 GMT. Stepping of the A/SPP for 600-line TV (positioning the solar panel toward the sun and the planar array toward the earth) was completed in less than one hour. The first 600-line TV sequence began at 03:41 GMT, and continued for 1½ h. Very good pictures were received which revealed a rough, rocky, uneven lunar highland area, quite different from the mare areas in which previous *Surveyors* had landed.

Lunar operations were conducted in accordance with the lunar operations plan as refined by the daily lunar operations planning meetings. A major problem, requiring revision to the plan, was experienced on January 10 when the ASI would not deploy from the background position to the lunar surface as commanded. A special analysis and test effort was performed to overcome a mechanical failure in the deployment mechanism, and the instrument was finally deployed on January 12, using the SM/SS to push the instrument to the lunar surface.

The SM/SS was subsequently used to reposition the ASI two additional times, providing data samples from three separate locations.

In general, spacecraft temperatures were higher than expected, and necessitated frequent cooldown periods with consequent delays to science activities. However, by judicious scheduling of lunar activities and close power/thermal management of the spacecraft, essentially all lunar objectives were accomplished. Total data acquisition included 20,993 video frames, 65 h and 44 min of alpha scattering data and 36 h and 21 min of surface sampler operations.

Following sunset at the spacecraft at 06:24 GMT on January 23, first lunar day operations were continued for an additional 79 h, 48 min until final shutdown at 14:12 GMT on January 26.

Table 20. Optional sequence for RF communications test

Day/time start of test:	015/14:54 GMT	
Supporting ground station:	DSS 42	
Initial conditions:	Transmitter A	Low power
	Antenna	Planar array
	Transponder power	A ON, B OFF
	Analog-to-digital converter	2
	Commutator	5
	Clock rate	1100 bits/s
	SCO	7.35 kHz PCM
	Omniantenna selected	B

Time, GMT	Command	Command title/data	Comments
14:54:03.5	0207	Presumming amplifier ON	
14:54:07.0	0504	Analog-to-digital clock rate 137.5 bits/s	
14:54:01.4	0204	Launch data radar altimeter ON	
14:54:12.9	0220	33.0, 7.35, 3.9-kHz SCO OFF	
14:54:25		DSS-received signal level −114.0 dBmW	Transmitter A unmodulated carrier
14:55.01.0	0500	0.96-kHz A/D SCO ON	Discriminator/decommutator lock
14:55:35		DSS-received signal level −119.8 dBmW	
14:55:55.6	0116	Transmitter B to planar array	Omniantenna B transmitted power 346 BCD[a]
14:56:15		DSS-received signal level −144.0 dBmW	
14:56:30.6	0120	Select omniantenna A	Omniantenna A transmitted power 321-315 BCD
14:56:35		DSS-received signal level −150.5 dBmW	
14:57:18.1	0102	Transmitter A filament power ON	
14:59:42.1	0125	Transfer switch A high power	
14:59:42.6	0103	Transmitter high voltage ON	Omniantenna A transmitted power 952-949 BCD
14:59:55		DSS-received signal level −132.16 dBmW	
15:00:15.6	0107	Transmitter high voltage OFF	
15:00:35.6	0121	Select omniantenna B	
15:00:44.1	0103	Transmitter high voltage ON	Omniantenna B transmitted power 925-922 BCD
15:01:00		DSS-received signal level −126.0 dBmW	
15:03:12.6	0107	Transmitter high voltage OFF	
15:03:19.1	0117	Transmitter A to planar array	
15:03:22.1	0103	Transmitter high voltage ON	
15:03:40		DSS-received signal level −102.2 dBmW	
15:04:31.6	0107	Transmitter high voltage OFF	
15:04:37.6	0126	Transfer switch A lower power	
15:04:40.1	0110	Transmitter filament power OFF	Confirmed
		DSS-received signal level −120 dBmW	
15:06:52.6	0214	Summing amplifiers OFF	Loss of data
15:07:01.1	0113	Narrowband VCXO OFF	
		Transmitter A wideband VCXO	
		Frequency drift measurements	
15:18:51.1	0112	Narrowband VCXO ON	
15:18:54.6	0210	PM summing amplifier A ON	
15:19:53.1	0210	Presumming amplifier ON	Discriminator/decommutator lock
15:20:41.6	0124	Transponder power OFF	Confirmed
15:21:15		DSS-received signal level −120.2 dBmW	
15:22:33.6	0123	Transponder B power ON	Transponder B phase-lock confirmed
15:35:55.2	0111	Transmitter low power OFF	
15:36:02.7	0104	Transmitter B lower power ON	
15:36:06.2	0112	Narrowband voltage controlled crystal oscillator ON	
15:36:09.7	0214	Summing amplifiers OFF	
15:36:20		DSS-received signal level −136.0 dBmW	
15:36:35.7	0207	Presumming amplifier ON	
15:36:38.7	0211	PM summing amplifier B ON	Discriminator/decommutator lock
15:36:35		DSS-received signal level −144.1 dBmW	Omniantenna B transmitted power 345-330 BCD (3 min)

[a]Binary-coded decimal.

13. Second lunar day operations. The first revival attempt on the second lunar day was initiated by DSS 61 approximately 130 h after sunrise at 19:00 GMT, February 12. The spacecraft responded immediately, terminating a shutdown period of 17 days, 5 h. An engineering assessment revealed a major power subsystem anomaly, however, which placed the spacecraft in a marginal survival category for the remainder of the lunar day and greatly limited operations. Other anomalies were:

(1) Landing leg 1 was collapsed, giving the spacecraft an 8-deg tilt away from the earth.

(2) Television in 600-line mode was inoperative. Tests indicated a failure in the camera 600-line horizontal sweep circuit.

(3) Alpha scattering instrument proton system inoperable.

Scheduled science operations were limited to two abbreviated activity periods on February 13 and 14. The TV camera was operative in the 200-line mode, however, and approximately 39 video frames of good quality were received. These included pictures of new, nearby surface areas revealed by the spacecraft tilt. Surface sampler operations were limited to a brief but successful test of the extension stepping capability of the instrument.

Because of the critical condition which developed in the battery, a decision was made to forego TV and SM/SS activities and preserve the spacecraft in favor of the alpha scattering experiment which was given first scientific priority. The ASI temperatures were above operating limits at this time due to the lunar noon. The spacecraft was successfully "nursed" through the next two days and power management techniques succeeded in producing a limited improvement in battery performance. Further degradation could not be prevented, however, and the battery lost its remaining capability on February 17. Solar panel current was sufficient to support alpha scattering operations, however, and more than 20 h of good alpha system data were successfully obtained.

Power management and operational experiments, accompanied by increasing loss of lock, continued until the carrier was lost for the final time at 00:24 GMT, on February 21. This preceded the predicted lunar sunset time by approximately 21½ h. Efforts to revive the spacecraft were continued until 06:48 GMT on February 21, when all search activities were terminated.

H. Summary of Deep Space Station Operations

The following pages comprise a summary of Deep Space Station operations for the *Surveyor VII* Mission. A description of the tabular columns follows:

(1) Acquisition/end of track (GMT), day of year, time: Each station entry in these columns consists of two sets of numbers. The first set is the day and time, in hours, minutes, and seconds, GMT, of spacecraft acquisition. The second set of numbers indicates the day and time that tracking terminated.

(2) Tracking, ground mode, length of time: These columns list the duration (in hours, minutes, and seconds) of each tracking ground mode. The ground mode indications, numerals 0–5, are defined in Table 21. At the end of each station entry is the total tracking time in all modes.

(3) Ground-received signal level, −dBmW. The ground received signal level column contains two figures for each station's entry. These figures are, respectively, the maximum and minimum signal levels received at the indicated station.

Table 21. Ground modes

Indicator	Ground mode
0	Transmit only
1	One-way (receive only)
2	Two-way coherent
3	Three-way coherent
4	Two-way non-coherent
5	Three-way non-coherent

(4) Television pictures received by command, noncommand: Unless otherwise indicated, these figures represent 600-line TV pictures received by a station while the spacecraft was under its command. Noncommand pictures are pictures received by a station while the spacecraft was commanded by another station.

(5) Significant events, equipment failures, and anomalies: As indicated, this column notes important events, equipment failures, and problems. All times given in this column are GMT in hours and minutes (four-digit numbers) or hours, minutes, and seconds (six-digit numbers).

The summary of Deep Space Station operations is contained in Table 22.

Table 22. Summary of Deep Space Station operations for Surveyor VII

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode[a]	Length of time			By command	Non-command	
Launch									
71	007	06:30:00.5 06:36:03	1 Total	00:06:02.4 00:06:02.4	131.0 158.0	0	0	0	Launch: 007 06:30:00.545 Azimuth: 102.914 deg
Launch pass									
51	007	07:04:53 07:08:38	1 Total	00:03:45 00:03:45	94.0 109.0	0	0	0	Spacecraft injection at 07:04:15
Pass 1									
Carnarvon, Australia	007	07:14:10 07:50:45	3 Total	00:36:35 00:36:35	096.0	0	0	0	Provided real-time telemetry data from 07:14:10 to 07:28:34 to DSS 42/SFOF
42	007	07:20:22 13:35:00	1 2 3 Total	00:06:38 04:33:00 01:35:00 06:14:38	88.7 128.2	52	0	0	Receiving real-time telemetry data from Carnarvon, Australia, from 07:14:10 to 07:28:34 TDH[b] VCO counter converter output level marginal between 07:22 and 07:39, causing incorrect exciter VCO counts on TDH. Converter output increased to give correct operation At 07:33, during initial spacecraft operations, command sequence 05:53 (transmitter high voltage off), the antenna acquired the spacecraft on a sidelobe which caused a delay in acquisition from 07:31:52 until 07:33:24 Transfer to DSS 51 at 007/12:00
51	007	11:31:22 22:24:11	2 3 Total	05:20:02 05:32:47 10:52:49	120.0 139.0	10	0	0	During pretrack, TDH doppler readings ceased. Replaced faulty doppler cable from receiver. Before and after spacecraft transfer to DSS 51, anomalous readings were noted in receiver doppler counter and at TDH. Lost 30 min of two-way data. Replaced doppler frequency shifter Spacecraft transfer to DSS 61 at 14:00 and DSS 11 at 21:20 GMT
61	007 008	12:55:40 01:33:28	2 3 4 Total	03:29:06 08:37:46 00:30:56 12:37:48	106.7 134.8	37	0	0	Data condition code of TDH reading incorrect for three-way doppler. Forced it manually into indicating three-way. Problem unresolved at this time CDC I/O operator did not have control of computer. Instead of stopping program, it was reloaded. Lost approximately 1 min of data

[a]Ground mode indications are defined in Table 21.
[b]Tracking data handling.

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, —dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 1 (contd)									
61 (contd)									Accomplished star map Spacecraft transfer to DSS 51 at 18:00 GMT on day 7
14	007 008	20:53:00 09:15:40	3 Total	12:22:40 12:22:40	107.8 126.9	0	0	0	Provided prime telemetry recording during midcourse phase and backup commanding capability to DSS 11
11	007 008	21:05:34 08:56:12	2 3 Total	08:10:02 03:40:36 11:50:38	115.7 135.2	82	0	0	Operator error. No pretrack calibration on mission support record tapes. Reset switch TDH punch 2 failure. Repaired punch Noisy doppler data during 1/10-s samples. Reset switch Midcourse maneuver completed at 23:38 GMT on day 7 Spacecraft transfer to DSS 42 at 05:30 GMT on day 8
Pass 2									
42	008	05:05:10 14:19:04	2 3 Total	07:15:00 01:58:54 09:13:54	135.0 138.7	016	0	0	Spacecraft transfer to DSS 51 at 12:45 GMT on day 8
51	008	12:30:27 22:34:15	2 3 Total	05:44:34 04:18:22 10:02:56	133.2 136.0	14	0	0	At 18:42 GMT receiver doppler counter reading incorrectly. Adjusted and operational at 18:56 GMT Spacecraft transfer to DSS 61 at 16:30 and 20:30 GMT
61	008 009	13:15:03 02:08:00	2 3 Total	04:00:04 08:52:53 12:52:57	134.5 146.0	8	0	0	Antenna off point at 17:51:56 and 00:14:17. Switched to aided track. Decommutator out of lock approximately 4 min Reel 2B off by mistake. Restarted recorder. No loss of data. Reel 2A included in data package Klystron replaced in low noise amplifier, maser 1 Spacecraft transfer to DSS 51 at 18:30 and DSS 11 at 22:30 GMT
14	008 009	21:02:37 09:36:40	3 Total	12:34:03 12:34:03	126.8 128.4	None	0	0	Lost 1 MHz reference to DSS 11 (blown fuse) Provided backup telemetry recording and commanding capability to DSS 11
11	008 009	21:18:18 09:11:12	2 3 Total	07:30:02 04:22:52 11:52:54	136.7 139.1	9	0	0	VCO count low and intermittent. Replaced frequency converter Magnetic tape failure. Replaced tape control power supply TDH punch 2 failure. Replaced punch Receiver 1 AGC isolation amplifier had low gain. Replaced amplifier

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 2 (contd)									
11 (contd)									TDH exciter VCO counter glitching. Replaced with spare counter HA low speed valve current low on negative axis. Replaced final amplifier module Second midcourse maneuver not required Spacecraft transfer to DSS 42 at 06:00 GMT
Pass 3									
42	009	05:25:48 14:28:50	2 3 Total	07:30:02 01:33:00 09:03:02	136.5 144.2	15	0	0	Spacecraft transfer to DSS 51 at 13:30 GMT
51	009	12:42:20 22:39:54	2 3 Total	06:00:04 03:57:30 09:57:34	136.2 140.0	26	0	0	TDH block found faulty during countdown with no 1 pulse/s printout. Trouble eventually traced to the 28-V battery supply which was only providing 14 V to TDH regulator. Hence, no 28 Vdc or 18 Vdc at TDH. An alternate 28-V source was connected. A new battery pack was substituted after track The day number display on TDH data failed to hold when advanced manually and stepping relays cycled through from zero upwards. Manually stepping the relays a few times from the back of the item counter cleared the fault and there was no recurrence of this anomaly From 14:04:06 to 14:10:36 accomplished frequency sweep to pick up spacecraft receiver A. Exciter went up and down 20 kHz (S-band) and station confirmed that receiver A AFC followed but the receiver A AGC was lower than expected Spacecraft transfer to DSS 61 at 15:30 and DSS 11 at 22:00 GMT
61	009 010	13:22:50 02:20:54	1 2 3 Total	02:00:56 02:28:50 08:28:18 12:58:04	121.8 156.7	2	0	15	Tape broke at start of last TV frame, FR-1400, reel 6B. Lost last frame, no vidio verification In three-way mode during touchdown phase Spacecraft transfer to DSS 51 at 18:00 GMT
14	009 010	21:05:17 10:01:45	3 Total	12:56:28 12:56:28	105.0 142.5	0	0	0	Provided prime telemetry recording during the touchdown phase and backup commanding to DSS 11 Dropped lock 5 min before retroignition. Made a check for sidebands. Operator did not recognize 96 kHz multiplexed data on the scope. Lost 2 min of data

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, —dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 3 (contd)									
14 (contd)									At 00:42:00, TDH sample rate to 1- and 10-s doppler resolver printout intermittently bad
11	009 010	21:31:45 09:37:00	1 2 3 4 Total	02:15:33 03:38:37 01:08:27 05:02:02 12:04:39	98.1 158.0	8815	1055[c]	160	Erroneous TDH exciter VCO readout. Replaced defective counter with spare unit. Received occasional glitches on VCO counter throughout pass Spacecraft touchdown at 01:05:37.6, at 40.89 deg S, 11.44 deg W Started 200-line video 46 min after touchdown Spacecraft transfer to DSS 42 at 08:00 GMT
Pass 4									
42	010	05:42:00 14:51:00	2 3 4 Total	05:14:42 02:54:00 00:58:55 09:07:37	117.5 125.4	1077	169	803	Alpha telemetry and command processor magnetic tape vacuum motor bearings seizing. Motor changed Command confirmation transmitted block of 407 commands twice from 12:07:29.9 to 12:12:05.5 Several communications processor outages occurred Alpha scatter activity Spacecraft transfer to DSS 61 at 14:15 GMT
61	010 011	13:35:03 03:15:20	1 2 3 4 Total	02:42:10 07:40:25 02:49:22 00:28:20 13:40:17	101.9 119.1	237	108	451	Unable to lock up discriminator to alpha scatter data during early part of track. Problem was at 550 and 1100 bits/s ASI deployed to background position Spacecraft transfer to DSS 11 at 22:25 GMT
11	010 011	21:56:00 10:19:15	1 2 3 4 Total	00:20:31 00:12:01 01:18:13 10:32:30 12:23:15	100.9 146.9	4658	751	108	ASI cannot be lowered to surface. Appears to be hung up on escapement mechanism. Trying to free ASI with the SM/SS At 04:38:00, mission support recorders missed one TV frame due to operator error. Sequence repeated and frame was recorded At 05:04:00, mission support recorders missed two TV frames due to operator error. Sequence was not repeated Spacecraft transfer to DSS 42 at 09:30 GMT
Pass 5									
42	011	06:42:00	2	00:43:32	113.6	5239	1261	121	CEC cooling fan unserviceable from 06:30 to 07:02 GMT. Replaced fan

[c]Includes fourteen 200-line TV pictures.

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 5 (contd)									
42 (contd)		15:23:00	3 4 Total	03:10:58 04:46:30 08:41:00	119.0				Computer failure at 07:05 GMT. Program reloaded Proton bit synchronizer had a fault which caused occasional parity errors on printout Alpha scatter activity Spacecraft transfer to DSS 61 at 15:00 GMT
61	011 012	14:14:08 04:14:50	1 2 3 Total	05:08:34 03:00:02 00:52:06 14:00:42	111.8 117.8	464	0	367	Alpha scatter and SM/SS activity Spacecraft transfer to DSS 11 at 23:00 GMT
11	011 012	22:55:00 11:08:00	2 3 4 Total	01:49:52 00:10:08 10:11:56 12:11:56	102.1 133.0	4441	601	31	From 07:00 to 07:05 GMT, quality of FR-800 video frames unknown. Adjusted head servo frequency control. FR-900 recorded good frames At 08:00 GMT, ASI deployed to lunar surface with a push from the SM/SS. Alpha scatter activity Film recorder jammed from 23:50 to 24:00 GMT Digital instrumentation subsystem A tape punch registration off; holes were punched too close together CDC punch blew fuse. Replaced fuse Spacecraft transfer to DSS 42 at 10:40 GMT
Pass 6									
42	012	07:41:00 16:00:00	2 3 4 Total	00:32:40 03:29:00 04:16:42 08:18:22	114.1 115.5	3353	799	202	To obtain correct sync, tip amplitude during video sequences, receiver VCO had to be off tuned to an acquisition voltage of −5 (200 kHz offset) Monitored ASI deployment to lunar surface by DSS 11 Alpha scatter and SM/SS activity Spacecraft transfer to DSS 61 at 15:30 GMT
61	012 013	14:55:06 05:06:25	1 2 3 Total	01:19:07 07:49:54 05:02:18 14:11:19	111.1 117.9	1396	294	597	During pretrack, Beta computer typewriter coupler intermittently would not interface. Switched alpha scatter to alpha computer and on-site program to Beta computer Alpha scatter and SM/SS activity

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 6 (contd)									
61 (contd)									Spacecraft transfer to DSS 11 at 00:10 GMT
11	012 013	23:50:00 12:00:00	2 3 4 Total	00:05:44 00:55:16 11:09:00 12:10:00	113.1 122.0	8160	846	33	FR-800 inoperative; video head would not revolve at 20:00. Operational at 02:02 GMT. Verified with TV-11 at 02:55 GMT Defective film (due to poor emulsion) noted at entrance to 70 mm camera. Not noted if prior exposed film was defective. Film roll duration from 15:30 GMT on day 11 to 02:00 GMT on day 13 Laser beam experiment during earth survey. No success Alpha scatter and SM/SS activities Spacecraft transfer to DSS 42 at 11:25 GMT
Pass 7									
42	013	10:50:00 16:48:00	2 3 4 Total	01:06:53 01:03:27 03:47:25 05:57:45	104.5 125.3	3198	984	0	Receiving approximately 5.2 dB discrepancy between DSSs 42 and 61 signal level readings. Requested DSS 61 to recheck AGC curve fits prior to next pass. At 16:24 GMT, DSS 61 reading was −118.6; DSS 42 reading was −123.7 dB Results of spacecraft WBVCXO carrier frequency measurements: receiver VCO 23.387525 Hz, demodulated zero receiver VCO 23.387742 Hz ASI activity Spacecraft transfer to DSS 61 at 16:20 GMT
61	013 014	15:42:01 02:00:00	1 2 3 Total	01:02:23 08:32:15 00:43:21 10:17:59	99.7 122.4	171	0	365	Digital instrumentation subsystem Beta computer typewriter running open at 00:21 GMT. Lost 1 min of data Received repeat on command confirmation from 21:06:55 to 21:09:37 and missed last command 01:34 at 21:09:56. Processor was putting out a header at that time Alpha scatter activity Spacecraft transfer to DSS 11 at 00:50 GMT on day 14
11	014	00:42:00 12:39:00	2 3 4 Total	01:25:23 00:14:36 10:16:51 11:56:50	95.0 122.0	5767	842	0	At 02:41:00, TV-11 missed first frame of video due to receiver operator error. At 02:41:15, configured receiver correctly Laser beam experiment unsuccessful SM/SS activity Spacecraft transfer to DSS 42 at 12:35 GMT

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 8									
42	014	11:44:00 17:46:00	2 3 4 Total	02:21:21 01:25:52 02:13:41 06:00:54	115.6 122.7	1910	382	138	At 15:46 GMT, during TV sequence using tape 241 (just after sequence 361), spacecraft ceased responding to commands for TV (i.e., command 1100 failed to produce video), spacecraft then commanded back to PCM. Transponder A had been left on prior to this video sequence. Unable to obtain good two-way lock due to apparent uplink sideband. Command modulation was then switched off for uplink search at which time ground receiver locked up one-way (i.e., two-way noncoherent). PCM data was bad, as camera power was still on (this command had not taken on, reconfigured spacecraft back to PCM). Camera power commanded off and PCM OK. A normal uplink search and two-way coherent lock was then performed. Subsequent TV sequences carried out with no problems but spacecraft transponder was switched off for these sequences. No explanation for above. No evidence of any transmitter or exciter malfunction At handover to DSS 61, still 4-dBmW difference in signal levels (6 dBmW for pass 007). Investigations have brought forth no explanation ASI activity Spacecraft transfer to DSS 61 at 17:10 GMT
61	014 015	16:39:24 02:30:00	1 2 3 Total	00:34:03 08:16:26 01:00:07 09:50:36	111.4 118.5	153	0	0	Commanded video; no TV received Alpha scatter activity Spacecraft transfer to DSS 11 at 02:00 GMT
11	015	01:36:00 13:47:00	2 3 4 Total	05:49:41 00:31:57 05:49:22 12:11:00	95.2 128.4	5874	995	0	At 05:50:38, on-site program command confirmation page print overline. Reloaded program. Operation appeared normal TV-11 missed first video frame after configuring for SM/SS. Receiver 2 was in 420-kHz telemetry bandwidth, instead of 3.3 MHz. Configured receiver 2 correctly Spacecraft transfer to DSS 42 at 13:40 GMT
Pass 9									
42	015	10:26:00 18:49:33	2 3 Total	04:50:00 03:33:33 08:23:33	101.1 151.2	199	0	300	Spacecraft receiver A AGC drifting and low signal level; receiver B normal At 12:15 and 12:46 GMT, had to reload computer program due to wrong identification entry on average alarm. Operator error Spacecraft transfer to DSS 61 at 18:30 GMT

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, —dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 9 (contd)									
61	015 016	17:37:50 07:50:55	0 1 2 3 Total	01:11:44 02:17:20 07:24:33 03:19:28 14:13:05	104.0 140.7	3843	0	0	Command 0232 transmitted in error at 20:59:06 *Surveyor V* (Pass 5-1) and *Surveyor VI* (pass 3-1) revival attempts unsuccessful from 00:19 to 01:55 GMT[d]. *Surveyor VII* in standby mode Center of lunar noon at 05:23 GMT Obtained two-way doppler from 07:10:54 to 07:40:30 Spacecraft transfers to DSS 11 at 03:00 and 07:40 GMT
11	016	02:35:00 14:41:00	1 2 3 4 Total	00:18:39 07:23:20 01:38:25 01:38:31 10:59:07	111.5 151.6	3629	356	0	During pretrack, spectrum analyzer was "red". Used test equipment as replacement Obtained two-way doppler for 30 min starting at 03:01:41 and 14:00 GMT At 03:22 GMT, antenna driving off spacecraft. Switched to aided track. At 04:10 GMT, back to auto track. Bad amplifier in integrator module From 04:35 to 05:44 GMT, unsuccessful attempts to revive *Surveyor V* (Pass 5-1) and *Surveyor VI* (pass 3-1). *Surveyor VII* in standby mode At 07:54:09, receivers out of lock. Loss of uplink to spacecraft transponder B At 09:00 GMT, TV-11 PCM bit errors excessive. At 09:55 GMT, temporary fix. Adjusted bit rate synchronizer for good PCM Spacecraft transfers to DSS 61 at 07:10, and DSS 42 at 11:15 and 14:35 GMT
Pass 10									
42	016	11:06:00 19:56:00	2 3 4 Total	02:41:34 03:28:24 02:36:10 08:46:08	111.4 142.5	76	0	0	On-site program failed to put new header on line for average alarm data when it should have. Operator was unsuccessful in two attempts to call up a new header. He then reassigned average alarm and everything was normal TDH exciter VCO printout had been invalid from start of pass at 11:06:00 until 15:20:02. Gain control on TDH frequency converter adjusted and VCO readout normal

[d]NSP-32, Spacecraft Revival, Rev. D, dated Sep 25, 1967, was used in all revival attempts.

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 10 (contd)									
42 (contd)									Obtained 30 min of two-way doppler starting at 11:16:23 Spacecraft transfers to DSS 11 at 11:50 and DSS 61 at 19:20 GMT
61	016 017	18:45:52 08:27:21	1 2 3 Total	04:21:12 08:43:00 00:34:58 13:39:10	111.5 141.2	324	0	338	Conducted multipath test Obtained two-way doppler from 07:51:43 to 08:20 GMT Alpha scatter activity Spacecraft transfers to DSS 11 at 03:40 and 08:20 GMT
11	017	03:24:30 15:34:00	2 3 4 Total	05:17:28 01:34:24 05:15:45 12:07:37	99.6 142.7	6661	860	0	Servo low-speed dec tachometer failed. No auto track capability Spectrum analyzer still out. Using test set for replacement Missed one frame of video on all recorders Obtained two-way doppler from 03:40 to 04:10 GMT and from 15:19:29 to 15:30:02 Conducted multipath test Spacecraft transfers to DSS 61 at 07:45 and DSS 42 at 12:10 and 15:30 GMT
Pass 11									
42	017	11:44:45 20:59:40	1 2 3 Total	01:00:26 05:10:02 03:03:46 09:14:14	100.2 142.3	2348	0	233	Klystron pump failure at 07:30 GMT, maser 2. Klystron replaced after post-track calibrations The FR-900 was tearing the picture on replay Obtained 30 min of two-way doppler starting at 12:10 GMT Spacecraft transfers to DSS 11 at 12:50 and DSS 61 at 20:00 GMT
61	017 018	19:50:30 08:52:53	1 2 3 4 Total	01:38:08 08:55:35 01:55:36 00:33:04 13:02:23	113.6 141.5	446	0	416	Special static phase error experiment SM/SS activity Spacecraft transfers to DSS 11 at 04:25 and 08:50 GMT
11	018	04:15:05 16:22:00	2 3 4 Total	05:17:27 01:26:49 05:22:39 12:06:55	111.3 142.9	8404	1220	0	First video frame missed due to receiver misconfiguration. Operator error. Reset 3.3 MHz bandwidth switch Digital instrumentation subsystem tape transport failed; approximately 45 min of doppler predicts lost. Replaced vacuum motor

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 11 (contd)									
11 (contd)									Spacecraft transfers to DSS 61 at 08:20 and DSS 42 at 12:40 and 16:15 GMT
Pass 12									
42	018	12:13:00 22:01:00	2 3 Total	05:45:02 04:02:58 09:48:00	111.5 143.0	2215	0	405	From 12:17 to 12:27 GMT, no one MHz signal on recorder A, track 4, due to a bad cable Obtained 30 min of two-way doppler starting at 12:40 GMT At 20:50 GMT, power generator 1 electronic governor failed, throwing 2 generator off line which placed all the load for the station U-buss on engine 1. Caused no problems as engine 1 could adequately carry the load Spacecraft transfers to DSS 11 at 13:20 and DSS 61 at 21:20 GMT
61	018 019	20:54:38 06:30:00	2 3 Total	08:11:30 01:23:52 09:35:22	111.9 148.9	32	0	0	Accomplished best-lock frequency measurement Obtained 30 min of two-way doppler starting at 05:00 GMT Spacecraft transfer to DSS 11 at 019/05:30 GMT
11	019	05:11:49 17:06:00	2 3 4 Total	01:34:59 00:54:09 09:25:03 11:54:11	99.3 141.7	6608	720	186	Receiving intermittent printout in the units of degrees position on TDH HA printout. Occurred originally at 11:15 GMT. Corrected by commutation module card replacement Receiver 2 acquisition isolation amplifier bad; replaced with spare At 14:54 GMT, TV-11 still receiving excessive PCM bit errors. Temporary fix by adjusting PCM bit synchronizer at 15:44 GMT Results of laser experiment undetermined SM/SS activity Spacecraft transfer to DSS 42 at 16:30 GMT
Pass 13									
42	020	15:57:00 22:35:00	2 3 4 Total	02:38:06 00:37:32 03:21:56 06:37:34	111.1 112.0	4791	1053	93	Traveling wave maser 2 warming up as of 06:00 GMT First two lines of TDH exciter VCO readout invalid during the data transfer test Command confirmation overprinting during TV commanding; average alarm disconnected

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT: Day of year	Time from acquisition to end of track, GMT: Time	Tracking: Ground mode	Tracking: Length of time	Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received: By command	TV pictures received: Non-command	Significant events, equipment failures, and anomalies
Pass 13 (contd)									
42 (contd)									TDH punch 1 jammed. Operator error Two video frames missed on FR-800 recorder. Reason unknown During posttrack calibrations, FR-1400 recorder B stretched and broke tape. Last 5 min of data lost. Re-recorded reel Spacecraft transfer to DSS 61 at 22:30 GMT
61	019 020	21:58:20 07:30:00	1 2 3 Total	00:48:14 08:01:16 00:42:10 09:31:40	112.1 144.5	2842	0	65	Command 0510 did not go out on confirmation at 03:04:29 High winds caused noise spikes in the RF system. Had to change bit rate from 1100 to 550 bits/s for telemetry and alpha scattering data Spacecraft transfer to DSS 11 at 06:30 GMT
11	020	06:14:00 17:53:00	2 3 4 Total	01:05:41 00:19:58 10:13:21 11:39:00	99.7 150.0	5336	846	120	TDH 1- and 10-s sample rate incorrect; Punch 2 punches every 5 s instead of every 10 s. Reset sample rate for format used Unable to monitor receiver 1 AGC on interim monitoring program from 06:13:36 to 07:14:03. Problem corrected by clearing tape punch before accomplishing AGC curve fit Program dump due to W buffer error. Reloaded program One frame of video lost due to mix up of incoming and outgoing crews Accomplished two laser beam experiments successfully SM/SS activity Spacecraft transfer to DSS 42 at 17:25 GMT
Pass 14									
42	020 021	16:52:09 00:13:00	2 3 4 Total	02:53:12 01:14:53 03:11:50 07:19:55	95.0 115.0	5795	1297	106	Maser 2 cool. Gain of 37.2 dBmW. Gain stability plot commenced at 02:05 GMT Alpha scatter activity Spacecraft transfer to DSS 61 at 23:30 GMT
61	020 021	23:06:23 08:40:00	1 2 3 Total	00:37:39 07:40:49 01:15:09 09:33:37	115.7 114.2	116	0	64	Servo pump 2 still down Alpha scatter activity Spacecraft transfer to DSS 11 at 07:30 GMT

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 14 (contd)									
11	021	07:14:52 18:21:00	2 3 4 Total	00:47:00 00:23:36 09:55:32 11:06:08	96.5 118.2	3953	672	321	At 11:30 GMT, loss of PCM data on mission support recorders since beginning of pass due to improper patch in CDC area. At 11:35 GMT, corrected patch, data to recorders normal ASI moved to second location by SM/SS Accomplished one laser beam experiment successfully ASI and SM/SS activities Spacecraft transfer to DSS 42 at 17:20 GMT
Pass 15									
42	021 022	16:51:52 01:14:00	1 2 3 4 Total	00:28:08 02:17:36 00:38:13 04:57:23 08:21:20	111.4 120.0	7651	1838	71	Digital Beta monitoring program hang up. Priority flip-flop failure In OSAS log, all record numbers to be decremented by one From 19:23 to 21:35 GMT, many communications processor outages Alpha scatter activity Record number of TV frames in a pass for DSS 42 Spacecraft transfer to DSS 61 at 00:35 GMT
61	022	00:19:23 09:35:30	2 3 Total	07:55:35 01:20:32 09:16:07	118.3 137.2	302	0	0	Servo pump 2 still has the leak OSAS record 16, time 07:15:05, not put on magnetic tape; the break point switch slipped. Restarted new accumulation 16 at 07:29:30. Tape data are retrievable on FR-1400 Alpha scatter activity Spacecraft transfer to DSS 11 at 08:30 GMT
11	022	08:19:00 18:49:00	2 3 4 Total	02:07:42 00:30:28 07:50:24 11:28:34	113.7 123.4	5274	966	391	On-site program blew. Reloaded program ASI moved to third location by SM/SS. ASI activity Spacecraft transfer to DSS 42 at 17:25 GMT
Pass 16									
42	022 023	13:58:00 02:26:00	1 2 3 4 Total	03:08:00 05:11:00 00:49:00 03:20:00 12:28:00	112.2 121.3	5360	1184	692	Backup TDH punch 1 failed to punch level 3 and 4 from 15:00 GMT to 22:43:02 at 60-s samples Uplink lost from 00:05:35 to 00:09:23 after changing to track sync frequency from 36:90 to 37:90 Hz at 0001. Correction made to track sync frequency

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT: Day of year	Time from acquisition to end of track, GMT: Time	Tracking: Ground mode	Tracking: Length of time	Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received: By command	TV pictures received: Non-command	Significant events, equipment failures, and anomalies
Pass 16 (contd)									
42 (contd)									ASI activity Spacecraft transfer to DSS 61 at 02:00 GMT
61	023	01:42:44 11:05:00	2 3 4 Total	02:52:34 01:50:12 04:39:23 09:22:09	120.1 126.7	2240	350	109	Alpha scatter activity Spacecraft camera sunset (sunlight off the camera) at 06:06 GMT. Solar panel sunset (zero solar panel current) at 06:24 GMT. No transfer with spacecraft in standby mode
11	023	09:31:14 19:12:00	4 Total	09:40:46 09:40:46	116.1 120.8	2906	496	6	ASI and SM/SS activities Spacecraft transfer to DSS 42 at 18:30 GMT
Pass 17									
42	023 024	14:30:00 02:14:00	0 1 2 4 Total	00:35:00 04:30:00 01:56:00 02:36:00 09:37:00	110.0 115.5	981	48	133	SSAC requested an investigation of one video frame which had a suspect sync tip amplitude from a special point at 19:39:15. Posttrack, this frame was checked on the FR-800, FR-900, and the FR-1400 and no anomalies were found A/SPP commanding. No spacecraft transfer accomplished[e] in standby mode (02:48 to 03:08 GMT).
61	024	03:03:00 10:40:00	0 1 2 Total	03:54:53 00:28:12 01:24:44 05:47:49	110.4 111.1	77	0	0	Spacecraft warmup and shutdown activity Accomplished best-lock frequency measurement
11	024	11:31:09 14:40:00	2 4 Total	00:28:44 00:08:05 00:36:49	110.5 110.6	41	0	0	Antenna pointing subsystem would not display "0" in second mission support record Receiver 1 AGC isolation amplifier noisy. Replaced amplifier Accomplished best-lock frequency measurement
Pass 18									
42	024 025	15:52:00 03:14:00	1 2 4 Total	09:14:00 00:53:00 00:16:00 10:23:00	108.7 142.0	100	0	0	
61	025	06:55:00 11:19:23	0 1	00:38:48 00:05:40	112.7 113.4	58	0	0	Spacecraft warmup and shutdown activity

[e]Next mutual view period with DSSs 42/61, pass 19, because of scheduling.

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 18 (contd)									
61 (contd)			2 Total	00:29:02 01:13:30					
11	025	15:03:49 15:16:16	4 Total	00:12:27 00:12:27	114.4 115.9	16	0	0	Mission support record FR-1400A even head frequency response out of tolerance at approximately 60 kHz. Replaced with spare
Pass 19									
42	025 026	16:22:00 05:46:00	0 2 3 4 Total	00:55:30 08:20:00 00:07:26 04:01:00 13:23:56	110.5 113.0	128	0	0	At 16:25 GMT, noted exciter VCO readout on TDH page print was reading zeroes for 7 min due to marginal trigger level. Readjusted level, and operational at 16:32 GMT Doppler resolver reading invalid until 18:35 GMT. Fault found to be incorrectly positioned mode switch on resolver counter At 19:02 GMT, TDH sample omitted (with track's permission) to reset the trigger level on resolver counter No transfer during this last DSSs 42/61 scheduled mutual view period
61	026	05:34:46 13:11:00	1 2 Total	03:18:46 04:17:27 07:36:13	113.6 135.6	108	0	0	Maser 1 down at 08:40 GMT. Suspected bad valve in crosshead. Used maser 2. No time lost in tracking Spacecraft warmup and shutdown activity
11	026	13:50:36 14:14:00	2 4 Total	00:02:28 00:20:56 00:23:24	119.0 133.0	16	0	0	During pretrack, lost phase 1, 440 V at 11:00 GMT. Found loose wire and corrected problem at 12:20 GMT Accomplished spacecraft transmitter/receiver best-lock frequency measurements from 14:03:23 to 14:09:51 Spacecraft shutdown at 14:12:07. First lunar day/night operations completed at 14:14 GMT

First lunar day totals

Commands sent	TV pictures received: By command	TV pictures received: By noncommand
138,060	20,993[c]	7,449
	Total	28,442[c]

Alpha scattering data received: 63 h, 44 min

SM/SS operations: 36 h, 21 min

[c]Includes fourteen 200-line TV pictures.

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT: Day of year	Time from acquisition to end of track, GMT: Time	Tracking: Ground mode	Tracking: Length of time	Ground-received signal level, —dBmW (max, min)	Total commands sent	TV pictures received: By command	TV pictures received: Non-command	Significant events, equipment failures, and anomalies
Second lunar day, Pass 2-1									
61	043 044	18:50:00 02:26:00	0 4 Total	00:35:58 06:59:06 07:35:04	94.9 149.1	1935	0	0	Switching modules in DSN/MSFN interface J-box not operating electrically. Switched modules manually Spacecraft revival[d] on first minor command sequence, 3260, sent at 19:00:25. Receiver in lock at 19:00:56 From 19:03 to 19:15 GMT, receiver 2 unsuccessfully searched for carriers, *Surveyor V* (pass 6-1) and *Surveyor VI* (pass 4-1) Configured for video. No TV received Spacecraft transfer to DSS 11 at 02:00 GMT
Pass 2-2									
11	044	01:54:00 11:40:00	0 1 3 4 Total	01:25:00 00:06:10 00:04:58 08:09:52 09:46:00	110.5 144.8	4716	6[f]	0	CDC I/O typewriter hung up. Trouble corrected itself On transfer from DSS 61 at 02:00 GMT, transmitter drive not turned on until 02:00:10. Operator error Alpha scatter activity *Surveyor V* (pass 6-2) unsuccessful revival attempt, 07:10–08:35 GMT Spacecraft transfer to DSS 42 at 11:35 GMT
42	044	09:45:40 18:17:00	1 4 Total	02:06:20 06:25:00 08:31:20	113.6 146.8	401	0	0	A/SPP commanding Spacecraft transfer to DSS 61 at 18:00 GMT
61	044 045	17:37:14 04:00:00	1 4 Total	01:22:44 09:00:02 10:22:46	114.0 127.3	493	0	0	Video activity. No TV received Spacecraft transfer to DSS 11 at 03:00 GMT
Pass 2-3									
11	045	02:45:00 13:39:00	1 4 Total	00:14:23 10:39:37 10:54:00	114.4 114.5	749	39[f]	0	TDH punch 2 lost from 03:50 to 04:20 GMT; switched to punch 1. Problem cleared. Caused by jammed punch 2 mechanism Lost sample pulses to TDH from 04:24 to 07:06 GMT. Replaced J-1, PC-145. Lost 2 h and 41 min of tracking data FR-900 failed due to control track being dirty. Cleaned head and restored to operation. Missed two frames of 200-line TV

[d]NSP-32, Spacecraft Revival, Rev. D, dated Sep 25, 1967, was used in all revival attempts.
[f]Two hundred line TV pictures.

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 2-3 (contd)									
11 (contd)									Brief operation of SM/SS to set coarse timing, extend one coarse step Spacecraft placed in standby at 13:29:10
14	045	07:17:17 08:20:00	3 Total	01:02:43 01:02:43	106.8	0	0	0	Backup to DSS 11 to verify video. No video received
42	045	10:57:30 13:34:00	3 Total	02:31:40 02:31:40	114.2 114.7	0	0	7[f]	Seven frames recorded on FR-1400 although 10 frames were commanded by DSS 11 while in the mutual view period Due to low battery condition of spacecraft, DSS 42 released from track at 13:34 GMT during TV three-way with DSS 11 Approximate center of lunar noon at 14:12 GMT
61	045 046	21:17:15 00:33:00	4 Total	03:15:45 03:15:45	110.9 141.7	198	0	0	
Pass 2-4									
11	046	05:15:25 12:00:00	0 3 4 Total	00:03:25 00:29:58 06:14:37 06:48:00	112.9 114.7	138	0	0	*Surveyor VI* (pass 4-4) unsuccessful revival attempt from 03:58 GMT to 05:10:35 Spacecraft transfer to DSS 42 at 11:30 GMT
42	046	10:59:40 20:12:08	0 1 4 Total	00:29:05 00:32:28 08:10:55 09:12:28	112.0 114.6	54	0	0	Due to operator error, CDC command printout not switched on from 11:31:40 to 11:37:27. Ten commands did not appear on printout Spacecraft transfer to DSS 61 at 20:10 GMT
61	046 047	19:49:00 04:56:00	0 3 4 Total	05:44:26 00:21:00 03:01:34 09:07:00	112.8 125.0	283	0	0	Spacecraft in standby at 04:46:57
Pass 2-5									
11	047	04:37:00 13:12:00	0 1 3 4 Total	03:45:35 00:12:25 00:09:57 03:34:34 07:42:31	113.5 116.3	236	0	0	Spacecraft transfer to DSS 42 at 12:50 GMT

[f]Two hundred line TV pictures.

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, —dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 2-5 (contd)									
42	047	12:02:22 21:17:30	0 1 4 Total	03:03:02 00:35:24 05:36:42 09:15:08	112.8 116.0	216	0	0	Exciter VCO TDH printout invalid from 15:34 to 15:42 GMT. Receiver counter trigger level adjusted Numerous data outages attributed to communication failures between GSFC and JPL Spacecraft transfer to DSS 61 at 21:15 GMT
61	047 048	20:53:51 05:45:00	1 4 Total	00:26:07 08:25:02 08:51:09	127.0 116.1	8	0	0	Spacecraft transfer to DSS 11 at 05:40 GMT
Pass 2-6									
11	048	05:20:00 14:36:00	0 1 4 Total	00:32:45 00:25:58 08:17:17 09:16:00	115.2 116.5	70	0	0	Receivers (out of lock) 12:56:10 to 13:05:10, when A/SPP commands sent Spacecraft transfer to DSS 42 at 14:30 GMT
42	048	13:58:54 22:43:30	0 1 4 Total	00:27:02 00:34:36 07:33:00 08:34:38	114.0 115.5	302	0	0	Command confirmation repeating blocks of commands Spacecraft transfer to DSS 61 at 22:30 GMT
61	048 049	22:07:50 07:15:00	0 1 4 Total	00:36:13 00:37:08 07:53:49 09:07:10	124.0 118.2	148	0	0	Alpha scatter activity Spacecraft transfer to DSS 11 at 07:00 GMT
Pass 2-7									
11	049	06:15:00 15:40:00	1 4 Total	00:54:58 08:30:02 09:25:00	119.0 126.4	108	0	0	Alpha scatter activity Spacecraft transfer to DSS 42 at 15:30 GMT
42	049 050	14:51:42 00:03:00	1 4 Total	01:23:19 07:47:59 09:11:18	112.0 143.0	83	0	0	Uplink to both spacecraft receivers lost at 19:29:17, reacquired at 20:07:29. Reset track sync frequency from 3550 to 3669 Hz at 20:21:50. Dynamic phase error fluctuated violently prior to loss of uplink Alpha scatter activity Spacecraft transfer to DSS 61 at 23:50 GMT

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT		Tracking		Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received		Significant events, equipment failures, and anomalies
	Day of year	Time	Ground mode	Length of time			By command	Non-command	
Pass 2-7 (contd)									
61	049 050	23:30:35 07:42:00	1 4 Total	00:21:23 07:50:02 08:11:25	128.8 145.0	142	0	0	Alpha scatter activity Spacecraft transfer to DSS 11 at 07:40 GMT
Pass 2-8									
11	050	07:17:43 17:05:30	1 4 Total	00:22:17 09:25:30 09:47:47	132.3 134.9	43	0	0	At 16:35:00, telemetry and command processor vacuum pump motor inoperative on computer A. Replaced with motor from telemetry and command processor B. No loss of data Alpha scatter activity Spacecraft transfer to DSS 42 at 17:00 GMT
14	050	07:23:40 16:59:04	3 Total	09:35:24 09:35:24	122.6 125.4	0	0	0	At 08:27:15, receiver out of lock, antenna out of optical lock. Reason undetermined Telemetry on all tapes recorded in frequency shift mode instead of direct
42	050 051	15:58:00 01:24:00	1 3 4 Total	00:14:00 01:02:00 08:10:00 09:26:00	128.0 131.6	118	0	0	Interim monitoring program unservicable Loss of communications from DSS 42 to JPL. Station configured to TTY conference mode from 00:27 to 00:38 GMT Alpha scatter activity Spacecraft transfer to DSS 61 at 01:10 GMT
61	051	00:50:31 08:58:00	0 1 4 Total	00:06:38 00:28:14 07:32:37 08:07:29	134.6 144.8	25	0	0	During pretrack, continuous valve current in one direction on antenna servo. Changed plug-in amplifier Experimenting at various exciter VCO settings from 01:31:56 to 02:55:35. (Decreased power in 2 kW steps until transmitter off) Spacecraft transfer to DSS 11 at 08:50 GMT
Pass 2-9									
11	051	08:34:00 17:34:00	0 3 4 Total	04:11:46 00:17:25 03:32:41 08:01:52	140.5 151.4	304	0	0	Brief operation of SM/SS to set fine timing and extended two fine steps Lost spacecraft signal at 12:24:06. Revival attempt unsuccessful until end of track
14	051	08:59:50 17:32:55	3 Total	03:24:16 03:24:16	131.0 144.6	0	0	0	Monitored DSS 11 unsuccessful revival attempt on *Surveyor VII* from 12:24:06 to end of track

Table 22 (contd)

DSS	Time from acquisition to end of track, GMT: Day of year	Time from acquisition to end of track, GMT: Time	Tracking: Ground mode	Tracking: Length of time	Ground-received signal level, −dBmW (max, min)	Total commands sent	TV pictures received: By command	TV pictures received: Non-command	Significant events, equipment failures, and anomalies
Pass 2-9 (contd)									
42	051 052	16:42:00 02:22:00	0 2 4 Total	01:35:00 01:41:00 04:21:57 07:37:57	134.0 152.4	700	0	0	Digital instrumentation subsystem Beta failed due to W buffer error and magnetic tape runaway. Reloaded program Mission Control considered spacecraft activities terminated at 17:57 GMT. DSS 42 was asked to carry on independently RF contact established at 18:17, with receivers in lock at 18:46 GMT Accomplished engineering interrogation, alpha scatter activity, and brief operation of the SM/SS to set coarse timing; elevate one coarse step, left azimuth two coarse steps When the camera power was commanded on at 00:24:20, the receivers dropped lock. No further signals were received although NSP-32 was extensively cycled
61	052	02:28:00 06:48:00	0 Total	04:20:00 04:20:00		938	0	0	During precals, excessive residual noise on exciter sync loop. Replaced 5100A sync driver *Surveyor VII* revival attempts terminated at 06:48:00

Second lunar day totals

Commands sent	TV pictures received: By command	TV pictures received: By noncommand
12,408	45	7
Total	52	

All TV pictures received were 200 line

Alpha scattering data received: 34 h, 30 min

SM/SS operations: 0 h, 21 min

Lunar day	Commands sent	TV pictures received: By command	TV pictures received: By noncommand	Alpha scattering data received	SM/SS operations
1	138,060	20,993[e]	7,449	65 h, 44 min	36 h, 21 min
2	12,408	45[f]	7[f]	34 h, 30 min	0 h, 21 min
Totals	150,468	21,038	7,456	100 h, 14 min	36 h, 42 min
		Total pictures 28,494[g]			

[e]Includes fourteen 200-line TV pictures.
[f]Two hundred line TV pictures.
[g]Includes sixty-six 200-line TV pictures.

I. Station Tracking Summary

Figure 40 shows a profile of the DSIF mission activity from launch until the end of DSN-committed coverage. This figure contains: the periods each station tracked the spacecraft plotted against mission time from liftoff; the number of commands transmitted by each station during each pass; the number of TV pictures received by command by each station during each pass; and the number of hours of alpha scattering data received by each station during each pass. Table 23 presents the total number of commands sent by each station during the mission. The total number of TV pictures received by command and noncommand for each station is presented in Table 24. The three prime stations committed to support alpha scattering operations received a total of 58 h and 08 min of data. The total number of hours alpha scattering data received by each station during each pass is presented in Table 25.

1. Deep Space Station 71. DSS 71 support for the *Surveyor VII* Mission consisted of a DSIF–spacecraft compatibility test, an ORT, a spacecraft prelaunch countdown phase, and a postlaunch phase lasting through approximately the first 40 min of the mission.

The purpose of the DSIF–spacecraft compatibility test, performed during joint flight acceptance composite testing, was to verify the ability of the DSN to support the mission. Command telemetry and TV interfaces were exercised via the RF link.

The ORT, performed on January 4 and 5, 1968, consisted of processing simulated spacecraft data received prior to $T - 5$ min from JPL, routed via hangar AO, and from $T - 5$ through $T + 40$ min from KSC. The received data in both cases were 550 bits/s PCM, which were fed directly into the CDC decommutator. The data were then outputted in the normal manner back to the SFOF via teletype and high-speed data line.

During the prelaunch countdown on January 6, spacecraft data were received from hangar AO in the system test equipment assembly area. At $T - 5$ min, the data source was switched to 550 bits/s PCM from KSC. The KSC data consisted of various AFETR tracking stations, including *Centaur* telemetry link prior to liftoff. The KSC data were received until approximately $T + 40$ min.

During the spacecraft readiness test, countdown, and launch, the DSS 71 antenna was optically aligned with the spacecraft. The receiver was locked on the spacecraft during these tests until spacecraft visibility was lost. This served as a backup to the KSC data source.

2. Deep Space Station 11. The pioneer site of the Goldstone complex was used to track *Surveyor VII*. Backup tracking was provided by the Mars site with its 210-ft diameter antenna. Provision had been made to allow the CDC to utilize the Mars site equipment for commanding the spacecraft and receiving spacecraft telemetry.

The midcourse maneuver and terminal descent phases of the *Surveyor VII* Mission were the major events of the *Surveyor* mission to be commanded from Goldstone. The midcourse maneuver was accomplished during the first Goldstone view period. A second maneuver was anticipated but was unnecessary because of the accuracy of the first maneuver. Spacecraft and ground equipment performed flawlessly.

Terminal descent occurred during the third Goldstone view period. The spacecraft performed as expected to touchdown and was transmitting 200-line TV pictures some 45 min after touchdown.

There were no failures or anomalies in the CDC during the mission. A summary of the station's view periods is given in Table 26. Table 27 gives a summary of DSS 11 CDC activities.

a. Pass 1. The spacecraft was acquired at 21:05 GMT. During this pass, 82 commands were transmitted. The majority of these were required to perform the midcourse maneuver. A manual lockon was required for star lockon because of star intensity saturation. The remainder of the commanding concerned routine engineering interrogations and drift checks. The spacecraft bit rate was 1100 bits/s throughout the pass with the exception of the maneuver period during which the bit rate was increased to 4400 bits/s. End of tracking was at 08:56 GMT.

There were no CDC anomalies during the countdown or pass 1.

b. Pass 2. The second pass at DSS 11 was uneventful. Initial acquisition time was 21:19 GMT utilizing DSS 14. When DSS 11 acquired and had sufficient signal strength for good data, the CDC transferred to DSS 11 (21:28 GMT). Pass activity amounted to one engineering interrogation and one gyro drift check. Nine commands were transmitted to the spacecraft. End of tracking occurred

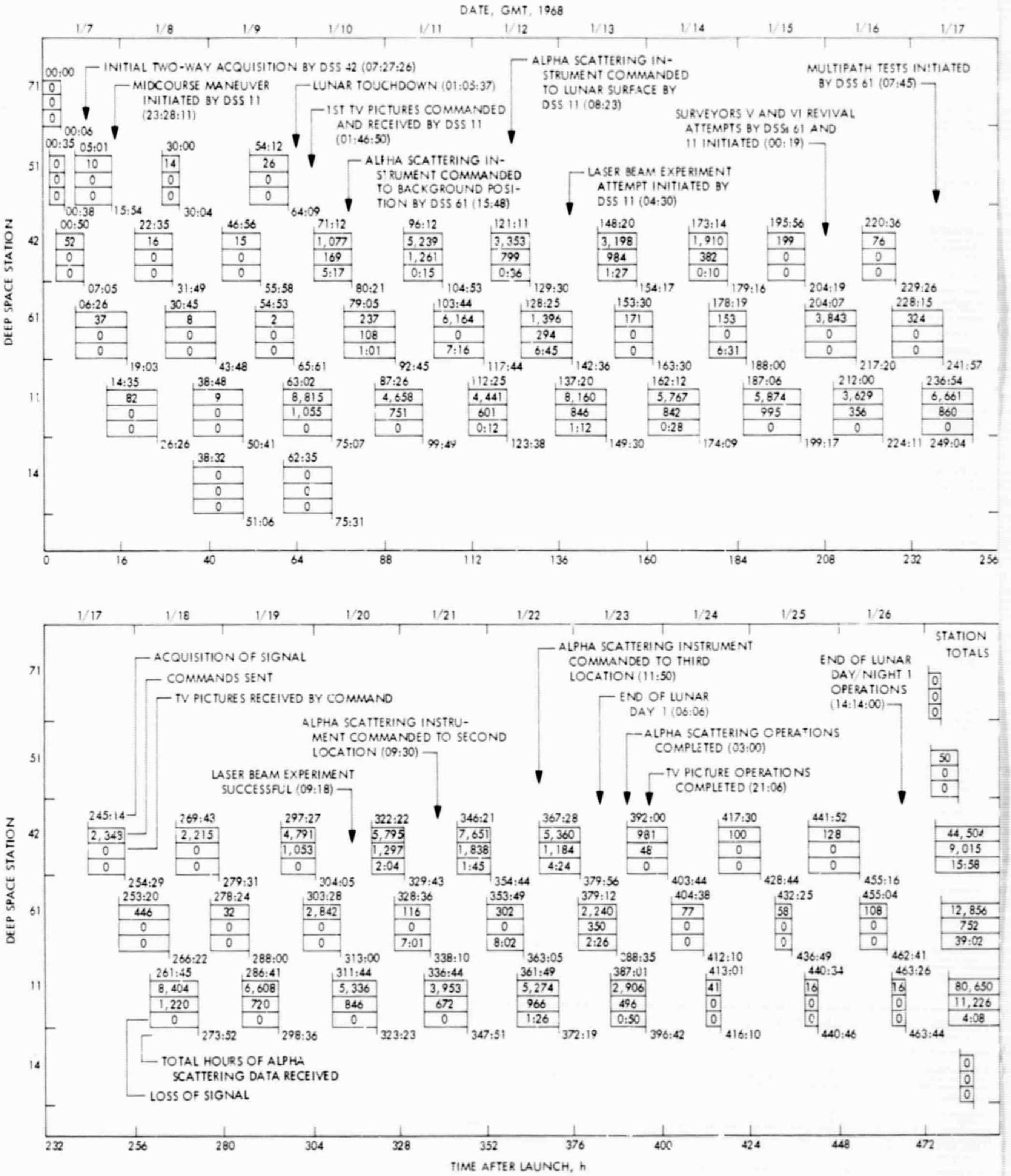


Fig. 40. Station tracking periods, first lunar day and night

Table 23. Commands transmitted by Deep Space Stations

Pass	Date 1968 (GMT)	Event	Commands transmitted			
			DSS 51	DSS 11	DSS 42	DSS 61
Launch	1/7					
01	1/7		0			
01	1/7				52	
01	1/7, 8					37
01	1/7, 8	Midcourse correction		82		
02	1/7		10			
02	1/8				16	
02	1/8, 9					8
02	1/8, 9			9		
03	1/8		14			
03	1/9		26		15	
03	1/9					2
03	1/9, 10	Lunar touchdown		8815		
04	1/10				1077	
04	1/10, 11	Alpha scattering instrument to background position				237
04	1/10, 11			4658		
05	1/11				5239	
05	1/11, 12					464
05	1/11, 12			4441		
06	1/12				3353	
06	1/12, 13					1396
06	1/13	Alpha scattering instrument moved to second location		8160		
07	1/13				3198	
07	1/13, 14					171
07	1/14	Laser experiment unsuccessful		5767		
08	1/14				1910	
08	1/14, 15					153
08	1/15			5874		
09	1/15				199	
09	1/15, 16	*Surveyors* V and VI revival unsuccessful				3843
09	1/16			3629		
10	1/16				76	
10	1/16, 17	Conducted multipath tests				324
10	1/17			6661		
11	1/17				2348	
11	1/17, 18					446
11	1/18			8404		
12	1/18				2215	
12	1/18, 19	Best-lock frequency measurements				32
12	1/19			6608		
13	1/19				4791	
13	1/19, 20					2842
13	1/20	Laser experiment successful		5336		
14	1/20, 21				5795	
14	1/20, 21					116
14	1/21			3953		
15	1/21, 22				7651	
15	1/22					302
15	1/22	Alpha scattering instrument moved to third location		5274		
16	1/22, 23	Spacecraft camera sunset			5360	
16	1/23					2240
16	1/23			2906		

Table 23 (contd)

Pass	Date 1968 (GMT)	Event	Commands transmitted			
			DSS 51	DSS 11	DSS 42	DSS 61
17	1/23, 24				981	
17	1/24					77
17	1/24			41		
18	1/24, 25				100	
18	1/25					58
18	1/25			16		
19	1/25, 26				128	
19	1/26					108
19	1/26	Spacecraft turned off		16		
Deep Space Station totals			50	80,650	44,504	12,856
Grand total				138,060		

Table 24. Television pictures received

DSS	Via station command	Via external command
71	0	0
51	0	0
42	9,015	3,297
61	752	2,356
11	11,226	1,781
14	0	0
Totals	20,993	7,434
Grand total	28,427	

at 09:01 GMT. A bit rate of 1100 bits/s was maintained throughout the pass. A marginal signal level at spacecraft receiver A resulted in periodic decoder cycling throughout the pass.

There were no CDC anomalies during countdown or pass.

c. Pass 3. The spacecraft was initially acquired at 21:06 GMT utilizing DSS 14; the spacecraft was transferred to DSS 11 data at 21:38. Events progressed nominally throughout the pass. Prior to the first maneuver, it was necessary to repeat a few commands because of decoder cycling. Terminal maneuvers were initiated at 00:29 GMT, and subsequent events occurred as scheduled.

Touchdown occurred at approximately 01:05:37 GMT. A modified postlanding sequence was accomplished, and the first 200-line TV frame was received approximately

Table 25. Alpha scattering data received by Deep Space Stations

Pass	Date 1968, GMT	Hours of data received		
		DSS 11	DSS 42	DSS 61
04	1/10		5:17	
04	1/10, 11			1:01
05	1/11		0:15	
05	1/11, 12			7:16
05	1/11, 12	0:12		
06	1/12		0:36	
06	1/12, 13			6:45
06	1/12, 13	1:12		
07	1/13		1:27	
07	1/14	0:28		
08	1/14		0:10	
08	1/14, 15			6:31
14	1/20, 21		2:04	
14	1/20, 21			7:01
15	1/21, 22		1:45	
15	1/22			8:02
15	1/22	1:26		
16	1/22, 23		4:24	
16	1/23			2:26
16	1/23	0:50		
Totals		4:08	15:58	39:02
Grand total			59:08	

45 min after touchdown. Fourteen 200-line frames were received. The A/SPP positioning was accomplished, and the remainder of the pass was devoted to 600-line TV and engineering interrogations.

There were 8815 commands transmitted to the spacecraft and 1055 video frames received (including 200-line frames). In addition, 169 video frames commanded by DSS 42 were received prior to the end of tracking at 09:30 GMT.

There were no CDC anomalies during countdown or pass 3.

The Pioneer site of the Goldstone complex continued tracking *Surveyor VII* throughout the first lunar day and into the lunar night. Spacecraft tracking operations were suspended January 26, 1968 at 14:12 GMT. The activity at this station emphasized commanding SM/SS operation and TV pictures. Alpha scattering data were accumulated and engineering interrogations were performed.

Operations during this period included the unique deployment of the SM/SS to force the ASI to the lunar surface after normal ASI deployment techniques failed, and the repositioning of the ASI to new locations on the lunar surface. In addition, a laser experiment was performed in which the spacecraft TV was successful in "seeing" laser light beams transmitted from earth. Excellent earth pictures were received throughout this operational phase.

d. Pass 4. This pass emphasized TV and SM/SS operations. The SM/SS operations were conducted with the station in a two-receiver configuration, with the CDC receiving telemetry only.

When the ASI failed to deploy from the background position to the lunar surface, the SM/SS was utilized to force deployment. Deployment of the ASI with the aid of the SM/SS was unsuccessful. Television was then utilized to survey the ASI for possible fault location.

During receipt of a command tape, the paper tape punch fuse failed. The fuse was replaced and normal operation was resumed.

During this pass 4658 commands were transmitted, including 751 TV frames.

e. Pass 5. This pass saw a repeat of the attempt to lower the ASI to the lunar surface utilizing the SM/SS. After apparently succeeding in the air deployment, a 10-min data accumulation was run which indicated the surface had not been reached. Subsequent deployment attempts were then attempted prior to transfer to DSS 42.

A total of 4441 commands were sent during this pass; 601 were TV frames.

Table 26. Summary of DSS 11 view periods

Pass	Date/time, GMT	No. of commands	CDC problems
1	Jan 7 21:05 8 08:56	82	No equipment problems
2	8 21:19 9 09:01	9	No equipment problems
3	9 21:06 10 09:30	8815	No equipment problems

Table 27. Summary of DSS 11 CDC activities

Pass	Date/start and finish time, GMT	No. of commands	TV frames	CDC problems	TFR No.
4	Jan 10 22:12 11 10:19	4658	751	Paper tape punch fuse blown	47769
5	11 22:55 12 10:40	4441	601	None	—
6	12 22:55 13 12:00	8160	846	None	—
7	14 00:42 14 12:39	5767	842	None	—
8	15 01:36 15 13:47	5874	995	Command subcarrier oscillator 2 had no output	47770
9	16 02:35 16 14:41	36[illegible]9	356	None	—
10	17 03:25 17 15:34	6661	860	None	—
11	18 04:15 18 16:22	8404	1220	None	—
12	19 05:14 19 17:06	6608	720	None	—
13	20 06:07 20 17:53	5336	846	None	—
14	21 07:17 21 18:21	3953	672	None	—
15	22 08:17 22 18:49	5274	966	Camera film counter switch intermittently chattered	4777[illegible]
16	23 09:31 23 19:12	2906	496	None	—
17	24 11:25 24 14:40	41	0	None	—
18	25 14:50 25 15:20	16	0	None	—
19	26 13:56 26 14:14	16	0	None	—

f. Pass 6. The ASI was found to be properly deployed. During this pass all scientific instruments were exercised. The ASI accumulation time totaled 52 min.

During this pass, 8160 commands were transmitted, including 846 TV frames.

g. Pass 7. A laser search was conducted during this pass without apparent success at the time. Three wide-band voltage controlled auxiliary oscillator checks were conducted utilizing spacecraft transmitter A. Rising temperatures necessitated a 50% duty cycle on TV operations.

During this pass, a total of 5767 commands, including 842 TV frames, were sent.

h. Pass 8. During countdown, command SCO 2 failed. The system tester 2.3-kHz SCO was patched and available for backup if command SCO 2 failed during the pass.

Operation of the spacecraft had been transferred to spacecraft transmitter B prior to DSS 11 acquisition. Operation continued on transmitter B throughout the pass.

During execution of command tape 202, the camera failed to respond to all positioning commands. No positioning errors were noted in subsequent TV operation.

During this pass 5874 commands were transmitted, including 995 TV frames.

i. Pass 9. Activity during this pass was limited because of high temperatures. Attempts were made to revive *Surveyors I, III, V,* and *VI*; all attempts were unsuccessful. *Surveyor VII* was then brought up on transmitter A, then transferred to transmitter B.

Command activity totaled 3629 commands with 356 pictures received.

j. Pass 10. Activity was again somewhat limited because of lunar noon temperatures. Both spacecraft transmitters were exercised, although spacecraft operations were predominantly conducted with transmitter B. The multipath experiment was conducted during this pass. Television deviation appeared greater during this pass than on the previous pass.

Commands transmitted during this pass totaled 6661, with 860 pictures received.

k. Pass 11. Activity during this pass consisted of TV operations and engineering interrogations. Temperatures did not present the problem anticipated; therefore, additional TV work was accomplished.

During this period 8404 commands were transmitted, and 1220 pictures were received.

l. Pass 12. The SM/SS operation was resumed during this pass, and a second attempt at the laser experiment was made.

Commands totaled 6608 during this pass, including 720 TV frames. An additional 186 pictures commanded by DSS 42 were received.

m. Pass 13. This pass emphasized SM/SS and TV operations. The laser experiment was conducted again and Space Science Analysis and Command indicated success.

During this pass, 5336 commands were transmitted, including 846 TV frames. An additional 120 pictures commanded by DSS 42 were received.

n. Pass 14. The spacecraft was returned to operation on transmitter A. The ASI operation was resumed in addition to normal TV and SM/SS operations. The ASI was moved to new site.

Commanding activity totaled 3953 commands, including 672 TV frames. In addition, 321 pictures commanded by DSS 42 were received.

o. Pass 15. This was a routine operational pass with the exception of moving the ASI to a third site.

During this pass, 5274 commands were transmitted, including 966 TV frames. An additional 391 pictures commanded by DSS 42 were received.

One problem occurred during this pass: the 35-mm camera film counter switch intermittently chattered and produced an erroneous footage count. Camera operation was not affected.

p. Pass 16. The spacecraft was already into the lunar night when acquired, although some lunar features were still illuminated. Television operations continued throughout the pass. Excellent earth pictures were received and the planet Mercury was photographed using the integrate mode of operation. The SM/SS was utilized to perform bearing strength tests. The ASI was turned on at completion of SM/SS operations, and data were accumulated until thermal restrictions prevailed.

Commands totaled 2906 during this pass, including 496 TV frames. An additional six pictures commanded by DSS 42 were received.

q. Passes 17, 18, and 19. These passes consisted of engineering interrogations and thermal control checks.

Command activity during these passes totaled 73 commands.

Pass 19 concluded the DSS 11 first lunar day track.

3. Deep Space Station 42. During the transit phase of the *Surveyor VII* Mission, DSS 42 had three tracking periods prior to touchdown. The station was in two-way lock with the spacecraft for 4 h and 33 min during the first pass (launch), 7 h and 15 min for the second pass, and 7 h and 30 min during the third pass. Eighty-three commands were transmitted to the spacecraft during the transit phase.

A summary of the DSS 42 view periods is given in Table 28.

Table 28. Summary of DSS 42 view periods

Pass	Date/time, GMT	No. of commands
1	Jan 7 07:20 13:35	52
2	Jan 8 05:05 14:19	16
3	Jan 9 05:25 14:28	15

a. Pass 1. The spacecraft was acquired at 08:21 GMT, and, after two-way lock was obtained, initial spacecraft operations were performed.

b. Pass 2. During pass 2, this station performed two engineering interrogations. The rest of the pass emphasized gyro drift checks.

c. Pass 3. As in pass 2, two engineering interrogations and several gyro drift checks consumed much of the commanding activity during pass 3.

During the first lunar day of the *Surveyor VII* Mission, DSS 42 tracked *Surveyor VII* for 13 passes prior to sunset and, three passes into the lunar night.

During the lunar phase of the *Surveyor VII* Mission 44,438 commands were transmitted to the spacecraft, and 12,312 TV frames were received, of which 9015 were commanded by DSS 42.

A total of 242 min of alpha scattering lunar surface information was accumulated, as well as 15 min of background information and 252 min of stowed data.

No equipment problems or failures occurred during the passes; therefore, no trouble/failure reports were raised for the mission.

The DSS 42 CDC anomalies encountered during this period are described in the pass summaries and are listed in Table 29.

d. Pass 4. Track began at 05:42 GMT with the station going two-way at 08:00 GMT.

The station was reconfigured for TV at 08:06 GMT, and narrow-angle sector 5 survey was commanded. From 08:29 to 08:51 GMT, narrow-angle pictures of the earth were taken using the various polarization filters.

At 09:06 GMT, the spacecraft was reconfigured for PCM and an engineering interrogation was performed. At 09:27, GMT alpha scattering operations commenced utilizing optional sequence 10, items 9.0–34.0. A total of 4 h and 12 min of ASI stowed information was accumulated.

At 10:12 GMT, A/SPP fine positioning started, with the A/SPP optimized at 12:24 GMT. An engineering interrogation completed the DSS 42 commanding for the pass at 13:40 GMT.

Transfer to DSS 61 occurred at 14:15 GMT, with end of track at 14:51 GMT. A total of 1077 commands were transmitted to the spacecraft, and 972 TV frames were received, including 169 commanded by DSS 42.

e. Pass 5. Track began at 06:42 GMT with the station going two-way at 09:30 GMT. The attempts by DSS 11 to free the ASI using the SM/SS were monitored prior to transfer, as were the earth pictures.

Table 29. Summary of DSS 42 CDC activities

Pass	Date/start and finish time, GMT	No. of commands	TV frames received		CDC problems
			DSS 42 command	DSS 11 command	
4	Jan 10 05:42 14:51	1077	169	803	None
5	11 06:42 15:23	5239	1261	121	None
6	12 07:41 16:00	3353	799	202	ESP[a] and TV on at same time causing loss of TV ID. ESP turned off before going on with TV survey, solving problem
7	13 10:50 16:48	3198	984	—	None
8	14 11:44 11 17:46	19[illegible]0	382	138	Spacecraft transponder dropped lock during a TV survey, causing TV not to respond to commands
9	15 10:26 18:49	199	—	300	Spacecraft receiver A had 20–30 dB AGC[b] variations and dropped AFC[c] lock
10	16 11:06 19:56	76	—	—	Same as pass 9, variations reduced to 10 dB by biasing predicts by +150 kHz
11	17 11:44 21:00	2348	—	233	None
12	18 12:13 22:01	2215	—	405	None
13	19 15:57 22:35	4791	1053	93	None
14	20 16:52 21 00:13	5795	1297	106	None
15	21 03:50 22 01:14	7651	1838	71	Filter wheel struck in mid-position for CT 803B 241 and part of 242
16	22 13:58 23 02:26	5360	1184	692	None
17	23 14:30 24 02:14	981	48	133	None
18	24 16:00 25 03:16	100	—	—	None
19	25 17:10 26 05:48	128	—	—	None

[a]Engineering signal processor.
[b]Automatic gain control.
[c]Automatic frequency control.

An engineering interrogation was performed at 09:34 GMT with the spacecraft configured for TV at 09:50 GMT. Focus ranging surveys were commanded from 09:57 GMT until 11:04 GMT.

After an engineering interrogation, a wide-angle 360-deg panorama was commanded from 11:11 until 11:33 GMT. At 11:37 GMT an engineering interrogation was performed.

At 12:00 GMT a narrow-angle 360-deg panorama was started, with the five segments completed at 14:09 GMT. The ASI was turned on at 14:19 GMT and an engineering interrogation was performed.

Transfer to DSS 61 occurred at 15:00 GMT with the end of track at 15:23 GMT. A total of 5259 commands were transmitted to the spacecraft, and 1382 TV frames were received, 1261 commanded by DSS 42. There were 15 min of ASI background information accumulated.

f. Pass 6. Track began at 07:41 GMT with the station going two-way at 10:40 GMT. During the three-way period DSS 42 was able to observe the final positioning of the ASI on the lunar surface using the SM/SS.

Commanding consisted of three engineering interrogations, a special survey of the rock field at the TV camera end stops, focus ranging at three different azimuths, and narrow-angle segment surveys of segments 1, 2, and the first half of segment 3.

Transfer to DSS 61 occurred at 15:30 GMT, with the end of track at 16:00 GMT. A total of 6353 commands were transmitted to the spacecraft, and 1001 TV frames were received, 799 commanded by DSS 42. There were 22 min of ASI lunar surface information accumulated.

A minor problem occurred at the start of the narrow-angle surveys. The engineering signal processor (mode 4) was left on causing loss of TV identification for the first TV frames. The initial command sequence for reconfiguring the spacecraft to TV turned off the processor (mode 5) leaving the mode the spacecraft was in (mode 4) on. The problem was rectified by sending command 0232 and continuing with the TV survey.

g. Pass 7. Track began at 10:50 GMT with the station going two-way at 11:25 GMT.

Commanding consisted of a special area survey, narrow-angle segment survey (segments 1, 2, 3, 4, and 5), the rock field at the camera end stops, and two engineering interrogations.

Transfer to DSS 61 was at 16:20 GMT with end of track at 16:48 GMT. A total of 3198 commands were transmitted; 984 TV frames were received, all transmitted by DSS 42. A total of 87 min of ASI lunar information was accumulated.

h. Pass 8. Track began at 11:40 GMT with the station going two-way at 12:35 GMT.

Commanding consisted of three engineering interrogations, photometric surveys of selected areas, a 360-deg wide-angle panorama including a special look at the ASI auxiliary mirrors, narrow-angle segment 1 survey, and alpha scattering turnon.

Transfer to DSS 61 occurred at 17:10 GMT with end of track at 17:46 GMT. A total of 1910 commands were transmitted; 520 TV frames were received, 382 commanded by DSS 42.

The only operational problem was dropping of the spacecraft transponder receiver lock about bubble 263 of tape 241 (narrow-angle segment 1). This caused a failure of the TV to respond to commands. When the spacecraft was reconfigured to PCM for troubleshooting, it was observed that mode 4 data were very erratic. It was concluded that the TV was still on, so command 1104 was transmitted, resulting in good mode 4 data. A normal uplink search resulted in capturing the spacecraft transponder. No evidence of DSS transmitted power difficulties or VCO malfunctions could be found. The remainder of the TV surveys were done with the spacecraft transponder off.

i. Pass 9. Track began at 10:26 GMT with the station going two-way at 13:40 GMT.

Commanding consisted of two engineering interrogations and optional sequences 16 and 17. No problems occurred during the sequences.

Transfer to DSS 61 occurred at 18:30 GMT. A total of 199 commands were transmitted; 300 TV frames were received, all while three-way with DSS 11. End of track was at 18:49 GMT. The only problem was a loss of receiver A automatic frequency control lock with the automatic gain control voltage for receiver A varying as much as 30 dB during the pass.

j. Pass 10. Track began at 11:06 GMT with the station going two-way at 11:15 GMT. After an engineering interrogation, the station transferred the command link back to DSS 11 at 11:50 GMT. Final transfer from DSS 11 occurred at 14:35 GMT. The purpose of the early transfer was to obtain two-way doppler information from the spacecraft while the rates were high early in the DSS 42 pass.

The remainder of commanding for the pass consisted of an engineering interrogation and RF link (multipath experiment) commands. The multipath experiments were designed to duplicate cyclic variations in the automatic gain control and frequency observed by DSS 11 just after *Surveyor VII* touchdown. All RF link combinations were tried in high power with only a half dB power level observed in a random fashion. The frequency stayed fairly constant on the narrowband voltage controlled crystal oscillator.

Problems again occurred with large variations in receiver A automatic gain control. After biasing the predicts by +150 kHz, the receiver remained in firm lock with the variations reducing to less than 10 dB.

Transfer to DSS 61 was at 19:20 GMT, with end of track occurring at 19:56 GMT. No TV was received. A total of 76 commands were transmitted.

k. Pass 11. Track began at 11:44 GMT with initial two-way transfer to DSS 42 at 12:10 GMT. Transfer back to DSS 11 was at 12:50 GMT and final transfer from DSS 11 occurred at 15:30 GMT.

An engineering interrogation was commanded at 15:30 GMT followed by a sequence to shade the TV camera at 16:28 GMT. At 18:00 GMT another engineering interrogation was commanded. From 18:25 to 19:22 GMT various commands were transmitted to turn on spacecraft loads in an effort to reduce the battery charge to a rate where the solar panel switch would stay on. Commanding for the pass concluded with an engineering interrogation at 19:25 GMT. Throughout the pass the switch tripped three times and was commanded back on each time.

Transfer to DSS 61 was at 20:00 GMT, with end of track occurring at 21:00 GMT. A total of 2348 commands were transmitted; 233 TV frames were received, all commanded by DSS 11.

l. Pass 12. Track began at 12:13 GMT with initial transfer from DSS 11 at 12:40 GMT. After commanding an engineering interrogation, transfer back to DSS 11 was at 13:20 GMT. Final transfer to DSS 42 was at 16:15 GMT.

At 16:28 GMT the A/SPP was stepped to provide shade on the TV camera. At 18:08 GMT the solar panel switch was commanded on. At 18:19 GMT filament A and touchdown strain gauges were turned on to reduce the battery charge current. Two more engineering interrogations completed the commanding for the pass.

Transfer to DSS 61 was at 21:20 GMT, with end of track occurring at 22:01 GMT. A total of 2215 commands was transmitted; 405 TV frames were received, all commanded by DSS 11.

m. Pass 13. Track began at 15:57 GMT with transfer to DSS 42 at 16:30 GMT.

Commanding consisted of three engineering interrogations on TV commands tapes 805, 801B (sequences 2, 3, 5, 7, and 8), 803B, 241 (starting at sequence 162), 242, 243, 245 (sequences 162 to 363, sequence 547 to 651), 202, and the special rock field survey at the camera end stops.

Transfer to DSS 61 was at 22:30 GMT with end of track occurring at 22:35 GMT. A total of 1146 TV frames were received, 1053 commanded by DSS 42. The total number of commands transmitted to the spacecraft was 4791.

n. Pass 14. Track began at 16:52 GMT with transfer to DSS 42 at 17:25 GMT.

Commanding consisted of two engineering interrogations, an alpha scattering calibration sequence (10A), and TV command tapes 202, 806, 801B, 803B, 241, 242, 243, 244, 245, and the special end stop coverage plus some narrow-angle earth pictures.

Transfer to DSS 61 was at 23:30 GMT, with end of track occurring at 00:13 GMT. A total of 1403 TV frames were received, 106 while three-way with DSS 11 and 1297 commanded by DSS 42; 5795 commands were transmitted to the spacecraft. There were 130 min of lunar surface ASI data accumulated.

o. Pass 15. Track began at 16:51 GMT with transfer from DSS 11 occurring at 17:20 GMT.

Commanding consisted of three engineering interrogations, solar panel stepping (70 step solar panel plus commands), an alpha scattering calibration sequence (10A), and TV command tapes 824 (at 5 different azimuths), 801B, 803B, 241, 242, 243, 244, 245, and 202.

An operational problem occurred during this pass in that the filter wheel stuck in half-way position for approximately the whole of command tapes 803B, 241, and the initial segment of 242. This was caused by transmitting the step filter wheel commands without waiting the proper interval between commands. The problem was difficult to detect because of the extreme shadow detail in the pictures. The filter wheel was reinitialized and the complete segment 2 narrow-angle survey was rerun.

Transfer to DSS 61 was at 00:35 GMT with end of track occurring at 01:14 GMT. A total of 1909 TV frames were received, 71 commanded by DSS 11 and 1838 commanded by DSS 42. A total of 7651 commands was transmitted. There were 90 min of lunar surface ASI information accumulated.

p. Pass 18. Track began with downlink lock at 16:00 GMT on day 24.

Commanding consisted of bringing up the spacecraft five times during the engineering interrogations, and transponder frequency measurements. Start/stop times for the standby-to-engineering interrogation back to standby were:

Time, GMT		
Start	Back to standby	
16:00	16:16	Day 24
17:59	18:14	Day 24
21:00	21:13	Day 24
00:00	00:17	Day 25
03:00	03:09	Day 25

End of track occurred with transmitter off at 03:16 GMT. No TV frames were received. A total of 100 commands were transmitted to the spacecraft.

q. Pass 19. Track began with downlink lock on day 25 at 17:10 GMT.

The initial commanding was an engineering interrogation. The shutdown sequence completed at 17:28 GMT left the spacecraft transmitter on wideband voltage controlled auxiliary oscillator with transponder B on, filament B on, and the AMR heater logic on to temperature balance loads.

At 19:30 GMT the spacecraft signal processing was turned on for a second engineering interrogation. Only modes 4 and 5 were accessed. The AMR heater logic was turned off and the spacecraft was left with transmitter B in wideband, transponder B on, and filament B on for the shutdown period starting at 19:37 GMT.

At 21:30 GMT the spacecraft was interrogated again, with all modes examined this time, including modes 3 and 6. Loads were again shifted, leaving the spacecraft shut down at 21:52 GMT with the transmitter B on narrowband voltage controlled auxiliary oscillator, transponder B on, and the AMR heater logic on.

On day 26 at 00:00 GMT the spacecraft signal processing was commanded on for an engineering interrogation. All modes were again cycled through. The shutdown loads were the same as interrogation 3 with the additional load of transponder A. Shutoff occurred at 00:28 GMT.

At 02:30 GMT the spacecraft signal processing was brought up for the fifth time for another look at all the commutator modes. Shutdown occurred at 02:45 GMT with the same loads as interrogation 4 remaining on.

At 05:00 GMT the last interrogation was started cycling through all the commutator modes. The shutdown left the same loads on, transmitter B on narrowband oscillator, transponder A and B, and AMR heater logic. The shutdown occurred at 05:10 GMT. The battery temperature had remained constant through the last three interrogations, indicating the loads were well selected.

At 05:25 GMT the signal processing was brought up in mode 5 for transfer to DSS 61. This was to allow DSS 61 to acquire the uplink with telemetry as their rise time was later than the DSS 42 5-deg transmitter off limit. The DSS 42 transmitter off time was 05:30 GMT.

A total of 128 commands were transmitted to the spacecraft. End of track occurred at 05:46 GMT. Table 30 gives the track summaries during the lunar phase.

4. Deep Space Station 51. DSS 51 had decommutator lock for only 4 min during the launch pass. During the additional three tracks, command activity at DSS 51 was rather minimal, consisting of the following:

(a) Seven engineering interrogations.

(b) One bit rate change (1100–550 bits/s).

(c) Three gyro drift checks.

Assorted commands were detailed in the view period summaries.

Fifty commands were transmitted from DSS 51 and all were accepted by the spacecraft. A summary of the station's view periods is given in Table 31.

a. Launch Pass. Although communications were poor at the time of launch, DSS 51 obtained the necessary information to acquire *Surveyor VII*. The decommutator was in lock for 4 min with the spacecraft in high power

Table 30. Track summaries, lunar phase

Pass	Date/start and finish time, GMT	No. of commands	TV frames: Commanded	TV frames: Not commanded	TV frames: Total	Alpha scattering time, min:s
4	Jan 10 13:35 11 03:15	237	108	451	559	339:00
5	11 14:14 12 04:14	464	0	367	367	449:59
6	12 14:55 13 05:06	1396	294	597	891	418:39
7	13 14:42 14 02:00	171	0	365	365	265:05
8	14 16:42 15 02:30	153	0	0	0	469:51
9	15 17:37 16 07:50	3843	0	0	0	—
10	16 18:45 17 08:27	324	0	338	338	—
11	17 19:50 18 08:52	446	0	416	416	—
12	18 20:54 19 06:30	32	0	0	0	—
13	19 21:58 20 07:03	2842	0	65	65	—
14	20 23:06 21 08.40	116	0	64	64	400:00
15	22 00:19 09:35	302	0	0	0	470:00
16	23 01:42 11:05	2246	350	109	459	140:00
17	24 03:08 10:40	77	0	0	0	—
18	25 07:00 11:23	58	0	0	0	—
19	26 05:34 13:11	108	0	0	0	—

Table 31. Summary of DSS 51 view periods

Pass	Date/time, GMT	No. of commands
1	Jan 7 11:32 21:20	10
2	Jan 8 12:34 21:56	14
3	Jan 9 12:47 22:00	26

with all systems appearing nominal during the necessarily quick analysis of the telemetry. The solar panel had stepped up about halfway to the transit position. No commands were transmitted from DSS 51.

b. Pass 1. The decommutator was in lock at 11:32 GMT with the spacecraft in mode 5 at 1100 bits/s. Transfer of spacecraft control from DSS 42 to DSS 51 occurred at 12:00 GMT.

It was noticed that the solar panel switch had gone off at about 12:05 GMT. This was reported to Mission Control. Command 0306 was transmitted at 12:27 GMT to turn the solar panel switch on. The switch went off again and command 0306 was again transmitted at 12:46 GMT.

Spacecraft control was transferred to DSS 61 at 14:00 GMT with the solar panel switch again off.

Star acquisition performed by DSS 61 was monitored by DSS 51. Decommutator lock was lost during the spacecraft roll maneuver. After the spacecraft was commanded back to 1100 bits/s, it was discovered that the receiver telemetry bandwidth had not been switched to 420 kHz during the 4400-bits/s operation.

Spacecraft control was transferred back to DSS 51 at 18:00 GMT with a gyro drift check in progress. An engineering interrogation was performed at 18:23 GMT. The gyro drift check was terminated at 19:10 GMT with commands 0704 and 0716. Control of the spacecraft was transferred to DSS 11 at 21:20 GMT.

Ten commands were transmitted from DSS 51 and accepted by the spacecraft.

c. Pass 2. Decommutator was in lock at 12:34 GMT with the spacecraft in mode 5 at 1100 bits/s. Control of *Surveyor VII* was transferred to DSS 51 at 12:45 GMT.

A gyro drift check was initiated by DSS 51 at 14:02 GMT. This check was terminated by DSS 61 after transfer of control.

Engineering interrogations were performed at 16:01 and 19:10 GMT from DSS 51 during two-way lock.

Spacecraft control was transferred to DSS 61 at 16:30, back to DSS 51 at 18:30, and back to DSS 61 at 20:30 GMT.

Command 0615 was transmitted at 20:05 GMT to turn on the vernier oxidizer tank 2 temperature control.

An engineering interrogation, commanded by DSS 61, was monitored at 21:56 GMT by DSS 51 while in three-way lock.

Fourteen commands were transmitted from DSS 51 and all were accepted properly by the spacecraft.

d. Pass 3. Initially, the decommutator lock was intermittent at 12:47 GMT during acquisition due to horizon noise. Solid lock was obtained shortly with the spacecraft in mode 5 at 1100 bits/s and DSS 61 in control.

Spacecraft control was transferred from DSS 61 to 51 at 13:30 GMT. At this time, some decoder switching was observed as the signal into receiver A was occasionally below indexing threshold. A dummy command, 3737, was accepted by the spacecraft at 14:00 GMT. It was decided to initiate a gyro drift check with command 0700 and turn on the compartment A heaters with command 0411.

An engineering interrogation was performed from DSS 51 at 14:14 GMT.

Spacecraft control was transferred to DSS 61 at 15:30 and back to DSS 51 at 18:00 GMT.

Engineering interrogations were performed at 18:07 and 20:58 GMT. At 18:10 GMT the survey camera electronics temperature control was turned on with command 1136. The bit error rate was checked with the following results:

Time, GMT	Bit errors/1000
18:08	0.36
19:21	0.71
19:36	0.63

At 19:56, the bit rate was reduced to 550 bits/s using command matrix 7B3.

Spacecraft control was transferred to DSS 11 at 22:00 GMT.

Twenty-six commands were transmitted by DSS 51; all were accepted by *Surveyor VII*.

Johannesburg operations were not committed for the *Surveyor VII* mission after touchdown.

5. *Deep Space Station 61.* DSS 61 operations during the transit phase were minimal, with most of the tracking period being three-way with DSS 51. The main exception to this was for star acquisition, which was performed by DSS 61.

Surveyor VII was tracked for three passes beginning at $T + 6$ h, 30 min until touchdown + 1 hr, 15 min. The operations crew was in for the launch and the complete event was monitored on the status net.

Star acquisition proceeded smoothly although it was necessary to use manual lockon.

Forty-seven commands were transmitted during the transit phase. There were no CDC equipment or operational problems.

Table 32 summarizes the DSS 61 view periods.

Table 32. Summary of DSS 61 view periods

Pass	Date/time, GMT	No. of commands
1	Jan 7 12:55 Jan 8 01:32	37
2	Jan 8 13:15 Jan 9 02:08	8
3	Jan 9 13:[illegible] Jan 10 02:20	2

a. Pass 1. *Surveyor VII* was acquired with decommutator lock at 13:00 GMT to begin the first pass with DSS 51 in control at the time. The station transfer to DSS 61 was executed at 14:00 GMT. An engineering interrogation was performed, followed by the star-acquisition procedure. During the roll maneuver, the automatic star lockon signal did not function properly. While rolling the second time, the spacecraft was stopped with the star in view by sending the sun lockon (reset roll latch) command at 14:14 GMT. After the gyros stabilized, the manual lockon command was sent and the Canopus error nulled out.

A gyro drift check was completed and another engineering interrogation was performed prior to transfer back to DSS 51 at 18:00 GMT. An engineering interrogation and gyro drift checks by DSS 51 were monitored until transfer to DSS 11 at 21:20 GMT.

A complete premidcourse sequence, midcourse maneuver, and postmidcourse sequence, executed by DSS 11, were monitored by DSS 61 prior to the end of tracking. End of tracking was at 01:32 GMT. Thirty-seven commands were transmitted during this pass.

b. Pass 2. The decommutator was in lock at 13:20 GMT to begin pass 2. Activity during this pass consisted of monitoring the spacecraft engineering interrogations and gyro drift checks.

Station transfers occurred as follows:

DSS		Time, GMT
From	To	
51	61	16:30
61	51	18:30
51	61	20:30
61	11	22:30

During the DSS 61 two-way tracking, the decommutator lost lock for a short period. The station antenna was in auto track and moved off the spacecraft signal for no apparent reason. The antenna was switched to aided track and moved back onto the signal and the decommutator was back in lock. The problem did not recur during this pass.

The end of the pass occurred at 02:08 GMT. Eight commands were transmitted to terminate one gyro drift check and perform one engineering interrogation.

c. Pass 3. Pass 3 began with decommutator lock at 13:30 GMT. DSS 42 was in control at the time but immediately transferred control to DSS 51. Station transfer from DSS 51 to 61 occurred at 15:30. A gyro drift check was terminated at 17:04, and transfer back to DSS 51 was executed at 18:00 GMT.

A parity error rate of 0.75 per 1000 bits was measured at 19:00 GMT. A bit rate reduction to 550 bits/s was commanded at 19:55 by DSS 51. Terminal descent sequences were all monitored, as were 200-line TV sequences after touchdown.

The end of tracking was at 02:20 GMT. Two commands were transmitted during two-way tracking.

DSS 61 continued to track *Surveyor VII* for 15 additional passes of lunar operation to complete the first lunar day for the mission.

As long as the instrument was operating (when temperatures were not elevated) DSS 61 activity was limited to accumulating ASI data. A TV sequence was also obtained as the instrument was deployed to the background position. Most TV activity, however, occurred while the station was tracking three-way.

Operationally, the most significant activity of this mission came as a result of lunar sunset occurring over DSS 61. Television shadow progression sequences were run until near sunset, and during one of these sequences it was realized that sunset would occur earlier than expected. Solar corona and other horizon pictures at sunset were obtained, as were temperature data in engineering modes.

During the lunar noon, when the spacecraft was too hot for much activity, *Surveyor VII* was put in standby and revivals of *Surveyors I*, *III*, V, and *VI* were attempted. These attempts were unsuccessful.

There were no CDC equipment problems during the entire mission and there were also no operational problems.

d. Pass 4. Pass 4 started with decommutator in lock at 13:38 GMT. Alpha scattering accumulations were in process at DSS 42, and DSS 61 started tracking in three way. Transfer to DSS 61 occurred at 14:15 GMT.

Preparation of an on-site command tape was requested to accomplish deployment of the ASI to the background position. The command tape consisted of deployment commands followed by 100 start frames with 2½-s delays between each start frame.

The ASI was deployed to the background position at 15:48 GMT in conjunction with special command tape to get video during instrument swinging. Total video during this sequence was 108 frames.

The telemetry was reconfigured for PCM at 16:04 GMT; bit rates of 1100, 137.5, and back to 1100 bits/s were exercised. The crew experienced expected interference in alpha scattering 70 kHz channel 0.960 kHz SCO during 137.5-bits/s operations.

Photographs of alpha scattering deployment sequences were examined in an effort to analyze possible objects that might have been under the instrument when it was deployed to the surface. Views of the surface were obtained at the farthest swing of the instrument. One small rock, apparently 2 in. in diameter, was visible in surface area of concern.

Some noise was observed in all discriminator band passes affecting bit error and synchronization of decommutator and alpha scattering ground equipment. Noise apparently came from ground microwave subsystem, and was coincident with large gusts of local winds. The noise did not seriously affect the quality of the data and was ignored.

An attempt was made to deploy the ASI to the lunar surface at 22:01 GMT. Deployment was apparently unsuccessful since no increase in alpha scattering channel activity was detected. Deployment commands were again attempted with no success.

A transfer to DSS 11 occurred at 22:25 GMT. The video of ASI was monitored which confirmed little movement of the instrument head.

The SM/SS mechanism was released followed by SM/SS operation with TV mode 4, then with TV mode 7. The station configured one receiver for TV and one for PCM telemetry. The transfer back and forth went very smoothly. Several attempts were made to jar the ASI to see if it would release. This included commanding the A/SPP in three axes, both plus and minus. At the end of this pass the instrument was still in the background position.

The total commands were 237, total video commanded 108, and total video received 451.

e. Pass 5. The pass began slowly with acquisition occurring as DSS 42 was completing TV operation; however, no pictures were received as commanded by DSS 42. Shortly thereafter, the spacecraft was returned to commutator mode 4. Station transfer was effected at 15:00 GMT and the remainder of the two-way tracking period was utilized for accumulating alpha scattering data in the background position. The alpha scattering operations were performed concurrently with interspersed engineering interrogations. The solar panel was stepped as required to keep pace with the sun.

After a station transfer to DSS 11, DSS 61 monitored TV and engineering operations until loss of signal.

During the pass, 464 commands were transmitted and 367 TV frames were received as commanded by Goldstone. In addition, 450 min of alpha scattering data were collected.

f. Pass 6. The pass started with acquisition at 15:55 GMT. DSS 61 was monitoring 600-line video as commanded by DSS 42.

Station transfer occurred at 15:30 GMT as DSS 61 continued the TV operations with completion of narrow-angle section 3, survey from sequence 354, and all of sector 5. Total TV frames commanded and received was 294.

Subsequent to TV operations, the alpha scattering subsystems were energized and alpha scattering and engineering interrogations consumed the balance of the evening. During the first alpha scattering calibration sequence, an intermittent signal from the calibration pulses was detected and reported. Subsequent analysis revealed no anomalies in the calibration spectrum or event rates. Scope triggering was suspected as the cause of the intermittent indication. This was verified during a later calibration sequence.

Total commands was 1355. Total TV frames was 873, of which 294 were commanded from DSS 61. Five hours and 18 min of alpha scattering data were accumulated, including two calibration sequences.

g. Pass 7. The decommutator was in lock at 15:49 GMT to begin pass 7. The bit rate was 1100 bits/s and the ASI was turned on. Two minutes later the bit rate was dropped to 550 bits/s with low modulation index subcarrier oscillator (SCO). Transfer from DSS 42 occurred at 16:20 GMT, and the first engineering interrogation was pe formed at 18:03 GMT. Alpha scattering data accumulations continued until 20:21 GMT, when the instrument was turned off because of excessive heating.

With the ASI turned off, the bit rate was increased to 1100 bits/s, dropped to 137 bits/s for accurate alpha scattering temperature readings, and then returned to 1100 bits/s. More engineering interrogations were executed with considerable switching between modes 4 and 5. The ASI was turned back on at 22:37 GMT and more data accumulations were made. Minor solar panel stepping was executed and a receiver zero beat frequency check in wideband mode was made.

Transfer to DSS 11 occurred at 00:50 GMT after which TV sequences were monitored until end of track at 02:00 GMT. DSS 61 track times were shortened by approximately 4 h, during DSS 11 overlap, for passes 7 and 8.

A total of 171 commands were transmitted and 365 TV frames received during DSS 11 overlap, and 4 h, 25 min of alpha scattering data were accumulated, including calibration data.

h. Pass 8. Pass 8 was a very quiet pass; alpha scattering data accumulation was the prime activity. Several engineering interrogations were performed during the data collection. A wideband frequency modulation frequency measurement was made on both the A and B transmitters. The A transmitter was near the limit of the ground receiver VCO, so it was decided to stay on the B string until further notice. Alpha scattering data accumulations were stopped and the instrument was turned off because of excessive heating.

Station transfer to DSS 11 was executed at 02:00 GMT, and DSS 61 was released from track at 02:30 GMT.

A total of 153 commands were transmitted and 6 h, 10 min of alpha scattering data were accumulated. There was no TV activity during this pass.

i. Pass 9. As pass 9 began, DSS 42 was just starting optional sequence 17. This sequence was being run through rather rapidly so it would be complete by transfer time, 18:30 GMT.

There was a minimum of activity during this pass as the spacecraft was very warm. Engineering interrogations were performed about every 2 h. At 00:30 GMT *Surveyor VII* was shut down and *Surveyors I, III, V,* and *VI* revival attempts were made until 01:50 GMT. These were only tried on transmitter A and no signal was detected.

Surveyor VII was turned back on, and the A/SPP was stepped around to shade the TV camera. At this time the transmitter was switched to the omniantenna and the bit rate was reduced to 550 bits/s. With this signal level (−137.5 dBmW) DSS 61 was still getting a parity error rate of 1.4/1000 bits.

Station transfer to DSS 11 occurred at 03:00 GMT.

At 04:40 GMT the spacecraft was commanded into standby and DSS 11 made further revival attempts for *Surveyors I, III, V,* and *VI*. At 07:10 GMT DSS 11 transferred back to DSS 61 for 30 min of doppler data. During this period the A/SPP was realigned to provide planar array operation.

Total commands sent to the spacecraft was 3843.

j. Pass 10. Pass 10 started with decommutation in lock at 18:47 GMT. Transfer from DSS 42 occurred at 19:20 GMT. Spacecraft temperatures were quite high during this lunar noon period, and, therefore, command activities were minimal and limited generally to engineering interrogations.

Transfer to DSS 11 occurred at 03:40 GMT. Total commands transmitted was 320. Total TV frames received was 338.

The track advisor questioned the voltage levels produced by the CDC demodulator during TV operations as FR-1400 magnetic tapes produced on station have shown overmodulation. Video checks were performed on the demodulator to prove all outputs were within specification. The phenomenon was interesting as premission analysis indicated that the spacecraft video sync tip would have a 2.3-V level; however, the DSS 61 demodulator was producing 2.7 V. The premission analysis is considered questionable as on-site equipment performance and operational procedures appear to be proper.

k. Pass 11. The decommutator was in lock at 19:55 GMT. DSS 61 was three-way with DSS 42. Transfer to DSS 61 occurred at 20:00 GMT.

Engineering interrogations were performed approximately every 2 h. A spacecraft best-lock frequency measurement, and movement of the A/SPP to shade the ASI constituted the only spacecraft activities due to high lunar noon temperatures.

The total number of commands was 446 and 416 TV frames were received.

Some 30 min of two-way doppler data were gathered just prior to DSS 61 set.

l. Pass 12. The decommutator was in lock at 20:55 GMT to begin pass 12 with station transfer from DSS 42 at 21:20 GMT. Activity during the pass consisted of four engineering interrogations at approximately 2-h intervals and a best-lock frequency test by the station. Transfer to DSS 11 occurred at 05:30 GMT with DSS 61 released from tracking at 06:30 GMT.

A total of 32 commands were transmitted during this pass.

m. Pass 13. At 22:00 GMT the decommutator was in lock to begin pass 13. As soon as station transfer from DSS 42 was complete at 22:30 GMT, the station performed a best-lock frequency check. Engineering interrogations about every 2 h were the prime activity during this pass except for extensive solar panel stepping. The signal was switched to the omniantenna at a low bit rate and the planar array moved to shade the TV camera. Just before transfer to DSS 11 the antenna was moved back and the bit rate increased.

Station transfer to DSS 11 occurred at 06:30 GMT after which SM/SS and TV activity were monitored. A total of 2842 commands were transmitted, and 65 TV frames were received before the station was released from track at 07:30 GMT.

n. Pass 14. Alpha scattering operation was once again activated after the instrument had cooled. Alpha scattering data were accumulated for the entire pass interspersed with engineering interrogations. One zero-beat frequency check in wideband frequency modulation mode was made on transmitter A. Station transfer to DSS 11 occurred at 07:30 GMT. After the spacecraft had been reconfigured, TV pictures of the earth commanded by DSS 11 were monitored. DSS 61 was released from track at 06:40 GMT.

A total of 116 commands were transmitted and 6 h, 40 min of alpha scattering data were accumulated. There were 64 TV frames commanded by DSS 11 that were received.

o. Pass 15. Pass 15 started with decommutator in lock at 00:19 GMT. Station transfer occurred at 00:35 GMT. Alpha scattering accumulations were made throughout the pass along with one standard calibration sequence. Several engineering interrogations were performed and the battery charge regulator was commanded first to the preregulated bus and then to the unregulated bus. At 01:34 GMT the PCM SCO was changed from 7.35 kHz (1100 bits/s) to the low mod index SCO (550 bits/s). The latter two commanding sequences were exhausted for decommutator stabilization. The solar panel was lagging the sun and it was necessary to step the solar panel to improve the charging rate.

Transfer to DSS 11 occurred at 08:30 GMT. The station sent 302 commands to the spacecraft, and 7 h and 50 min of alpha scattering data were accumulated including calibration time.

p. Pass 16. Lunar sunset occurred at 06:06 GMT during this pass; as a result, the pass was one of the busiest of the mission for DSS 61. The decommutator was in lock at 01:45 GMT and station transfer from DSS 42 occurred immediately after, at 02:00 GMT. Alpha scattering operation began before station transfer and was interrupted only for a TV shadow progression sequence at 03:00 GMT. A total of 2 h, 20 min of alpha scattering operation, including calibration, was completed before the second TV shadow progression sequence was started. During this shadow progression series it was noted that lunar sunset appeared to be much closer than anticipated.

Special command tapes that had been prepared earlier were used for the TV sequence for shadow progression and various filter wheel positions, which went very smoothly. Sunset on the camera was declared to be 06:06 GMT from verbal description of the TV polaroids and the camera was then moved around for the corona pictures. The remainder of the pass was spent running short engineering interrogations and many TV sequences.

Also included during this time were some SM/SS operations.

Despite the rush to accomplish as much as possible in as little time as possible everything went smoothly. The crew was very efficient. There were no equipment or operational problems during this pass.

Transfer to DSS 11 occurred with a nonstandard hurried transfer at 09:32 GMT and went very well. A total of 2240 commands were transmitted, including 350 TV frames commanded and received. An additional 109 TV frames from DSS 11 commanding were received before the end of this pass at 11:05 GMT.

q. Pass 17. By this time the spacecraft has been put in standby mode. Every 2 h during this pass the spacecraft was brought up for an engineering interrogation and then put back to standby. During the third wake-up a best-lock frequency test was performed. A total of four interrogations were run during this pass with a total of 77 commands transmitted.

r. Pass 18. The spacecraft was in standby mode at this point in the lunar night and engineering interrogations were performed approximately exery 4 h. First interrogation for this pass was at 07:00 GMT. Some telemetry values obtained during this interrogation indicated the thermal switch in compartment B had opened. The spacecraft was brought up at 08:30 GMT for a recheck and then put down at 08:32 GMT. At 09:05 GMT the spacecraft was turned on once again for certain electronic reconfiguration for thermal reasons and then shut off. The last wake-up and engineering interrogation for this pass was at 11:00 GMT. A total of 58 commands were transmitted.

s. Pass 19. On this, the last pass of the first lunar day, *Surveyor VII* was acquired first at 05:35 GMT in commutator mode 5. It was at that time being commanded by DSS 42, prior to DSS 42 set.

The spacecraft was turned on again at 07:30 GMT and an engineering interrogation of all commutator modes was performed. Also best-lock frequency measurements were made on telecommunications strings A and B.

Thereafter, for the remainder of the pass, the spacecraft was turned on at approximately 1-h intervals in commutator mode 5 to closely monitor the falling compartment temperatures.

A total of 108 commands were transmitted.

VI. Tracking and Data System Performance Evaluation

A. Near-Earth Flight Phase

The near-earth flight phase is that portion of flight that is within 10,000 mi from earth. The TDS near-earth phase network is comprised of those facilities and operations that were committed by the various agencies of the AFETR, GSFC/MSFN, DSN, and NASCOM to support the launch through DSIF acquisition. Thereafter, the DSN is solely responsible for spacecraft tracking and data acquisition functions.

1. Air Force Eastern Test Range. Being a part of the TDS near-earth phase network, the AFETR was to provide coverage for tracking (metric data), *Atlas/Centaur* telemetry (VHF), and *Surveyor* spacecraft telemetry (VHF and S-band), using land stations, range instrumentation ships and aircraft, as needed, to meet the commitments.

The TDS configuration for near-earth support of the *Surveyor VII* Mission is shown in Table 33. Earth tracks and anticipated coverage intervals are illustrated in Figs. 11 and 12.

Table 33. Tracking and Data System configuration for near-earth support of *Surveyor VII*

Station	Metric tracking	VHF telemetry	S-band telemetry
Kennedy Space Center	X	X	X
Cape Kennedy	X	—	—
Patrick AFB	X	—	—
Grand Bahama Island	X	X	X
Grand Turk	X	—	—
Antigua	X	X	X
Twin Falls	X	X	X
Ascension	X	X	X
Pretoria	X	X	X
Sword Knot	—	X	X
Bermuda	X	X	—
Tananarive	X	X	—
Carnarvon	X	X	X
DSS 71	—	—	X
DSS 51	X	—	X
DSS 42	X	—	X

a. Tracking. Estimated and actual radar coverages are shown in Fig. 41. All class I metric coverage requirements were met, with the actual coverage equalling or exceeding the estimate at most stations.

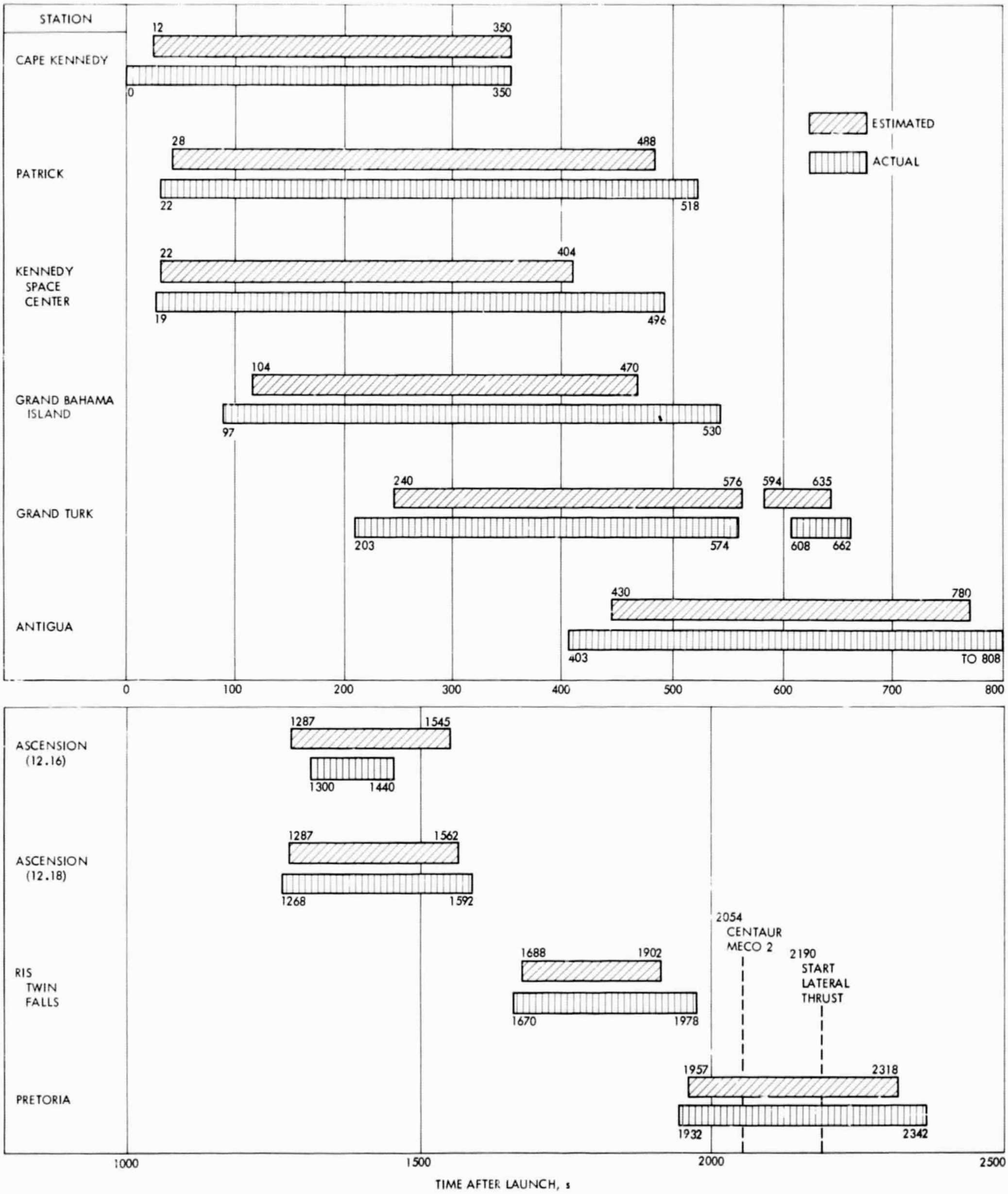


Fig. 41. Air Force Eastern Test Range radar coverage

A short dropout, attributed to balance point shift, occurred as predicted during the Grand Turk coverage interval. Redundant coverage from Antigua was available during the 34-s dropout.

Coverage from the Ascension 12.16 radar was less than predicted. This was attributed to low signal strength. Full coverage was obtained from the 12:18 radar at Ascension during this period.

b. Telemetry (VHF). Estimated and actual VHF telemetry coverages are shown in Fig. 42.

Continuous and substantially redundant coverage was provided, with the exception of the expected gap between Antigua and Ascension.

All VHF data were of good quality, with the exception of a noisy interval of data that was noted around spacecraft separation. Pretoria was the only station in view at this particular time.

Spacecraft data that were retransmitted in real-time were of good quality, and good launch vehicle telemetry was received in real-time from RIS *Twin Falls.*

Mark event times that were received and read out by AFETR and MSFN stations are shown in Table 34.

c. Telemetry (S-band). The estimated and actual S-band telemetry coverages are shown in Fig. 43.

Good S-band support was realized, both in receive/record and in real-time retransmission.

The actual coverage from KSC was about 100 s short of the estimated coverage. This has been experienced on past launches, but has varied with the launch azimuth. Coverage from each of the remaining stations and ships exceeded the estimates.

The AFETR capability for providing future launch vehicle and spacecraft S-band support has been demonstrated.

d. Surveyor real-time telemetry data. The AFETR configuration for spacecraft telemetry retransmission from the supporting stations and ships to building AO and DSS 71 is shown in Figs. 44–46.

The data were to be routed to KSC as shown in Figs. 44 and 45. There, after analysis by using the time division multiplexes, the AFETR telemetry coordinator would select the best source for transmission to building AO and DSS 71 via modems. As shown in Fig. 46, there are two modem lines between KSC and the X-Y building to provide redundancy.

The modem lines were bridged at the X-Y building to provide two modem lines each to building AO and DSS 71. The DSS 71 routes the data through a CDC and telemetry and command processor for further transmission to the SFOF via a NASCOM high-speed data line. This is the prime route to the SFOF. In addition, downrange data were relayed directly to the SFOF from Ascension, through the use of communication satellite circuits.

Table 34. Time of *Surveyor VII mark* events

Mark	Time, GMT	Source
Liftoff	06:30:00.545	Cape Kennedy
1	06:32:33.100	Kennedy Space Center
2	06:32:36.080	Kennedy Space Center
3	06:33:18.050	Kennedy Space Center
4	06:33:47.600	Kennedy Space Center
5	06:34:09.200	Kennedy Space Center
	06:34:08.900	Bermuda
6	06:34:11.400	Kennedy Space Center
	06:34:11.500	Bermuda
7	06:34:22.120	Kennedy Space Center
	06:34:21.900	Bermuda
8	06:39:53.700	Antigua
	06:39:53.800	Bermuda
9	06:39:54.600	Antigua
	06:39:56.000	Bermuda
10	06:41:09.5	
11	06:41:11.100	Antigua
12	07:01:51.700	
13	07:02:21.300	Pretoria
14	07:02:21.300	Pretoria
15	07:04:15.500	Pretoria
16	07:04:36.700	Pretoria
17	07:04:44.700	Pretoria
18	07:05:00.000	Pretoria
19	Not available	
20	07:05:16.500	Pretoria
21	07:05:20.000	Pretoria
22	07:06:30.900	Tananarive
23	Not available	
24	07:09:16.000	Tananarive
	07:09:15.700	*Sword Knot*
	07:09:16.000	Pretoria
25	07:13:26.800	Tananarive
	07:13:26.300	*Sword Knot*
	07:13:25.000	Carnarvon
26	07:15:06.500	Tananarive
	07:15:06.000	*Sword Knot*
	07:15:06.000	Carnarvon

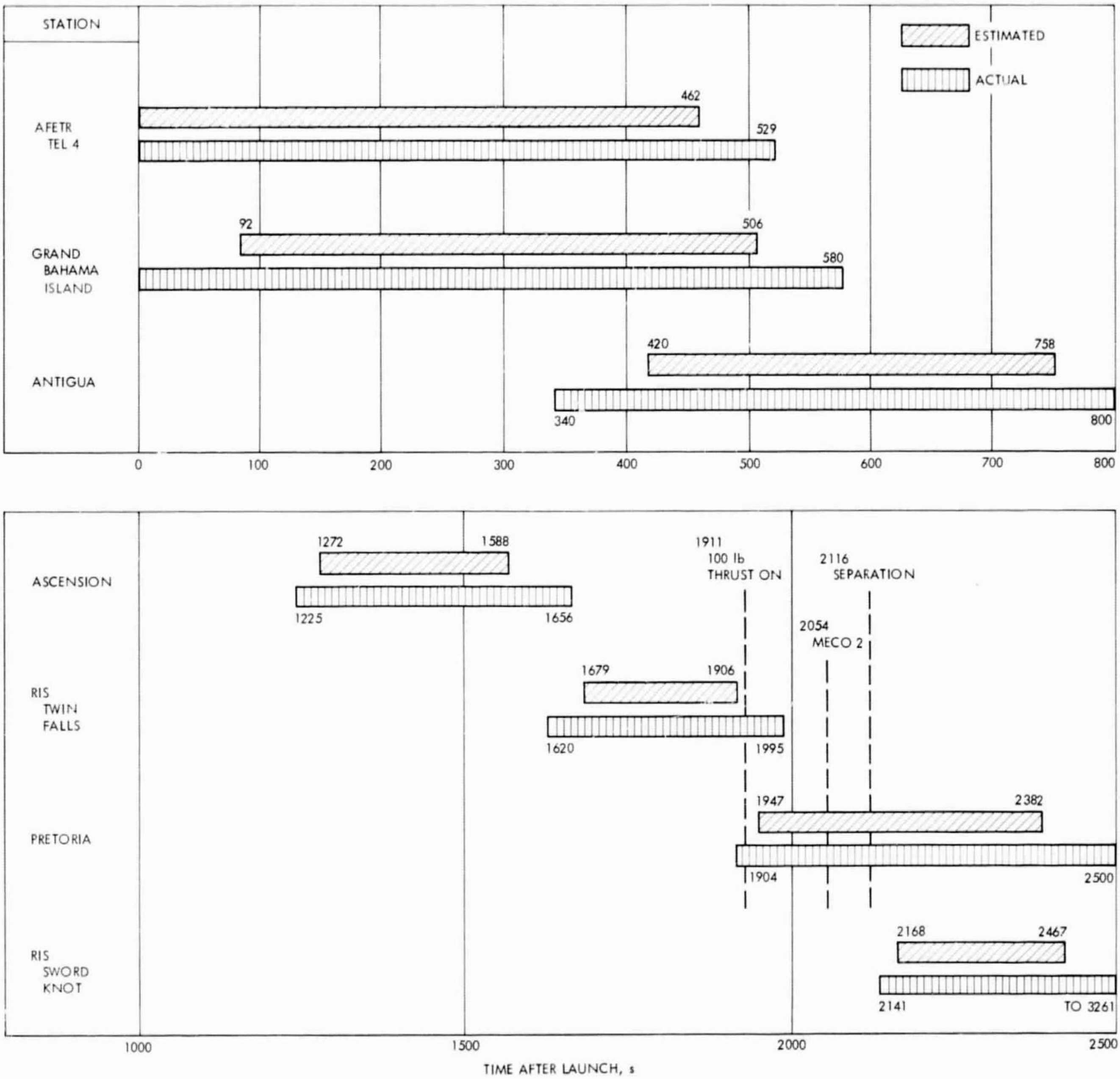


Fig. 42. Air Force Eastern Test Range VHF telemetry coverage

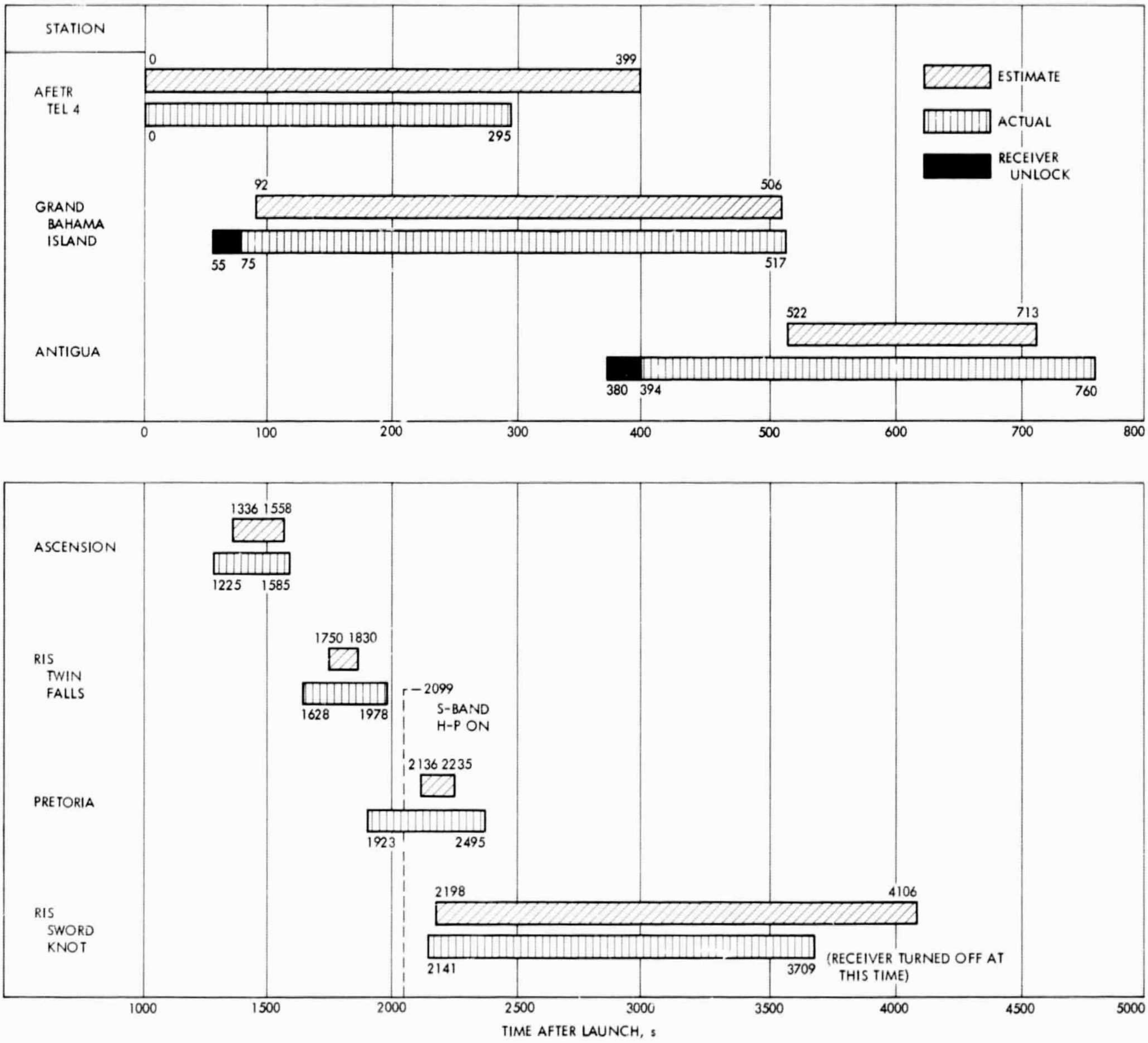


Fig. 43. Air Force Eastern Test Range S-band telemetry coverage

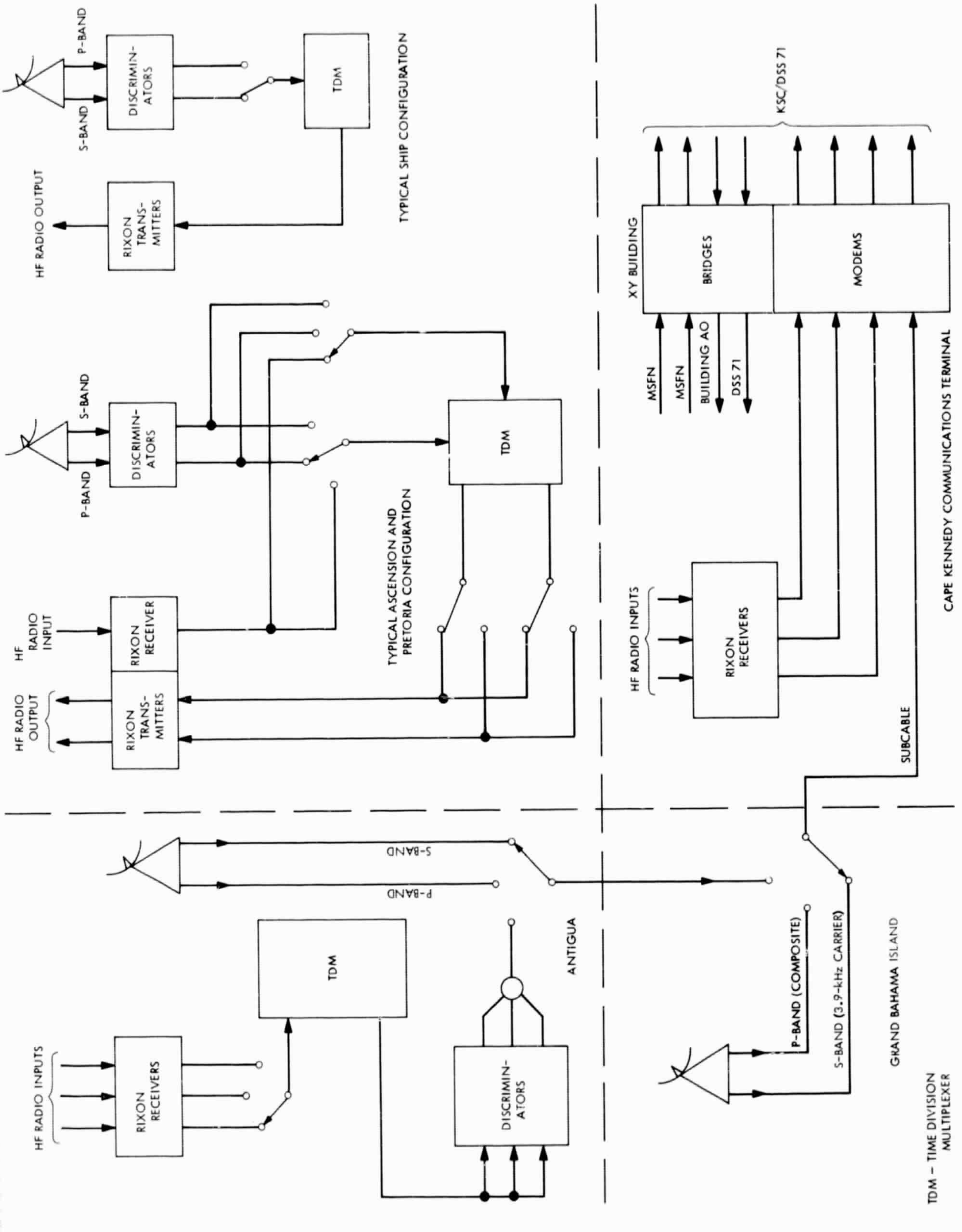


Fig. 44. Downrange telemetry data flow

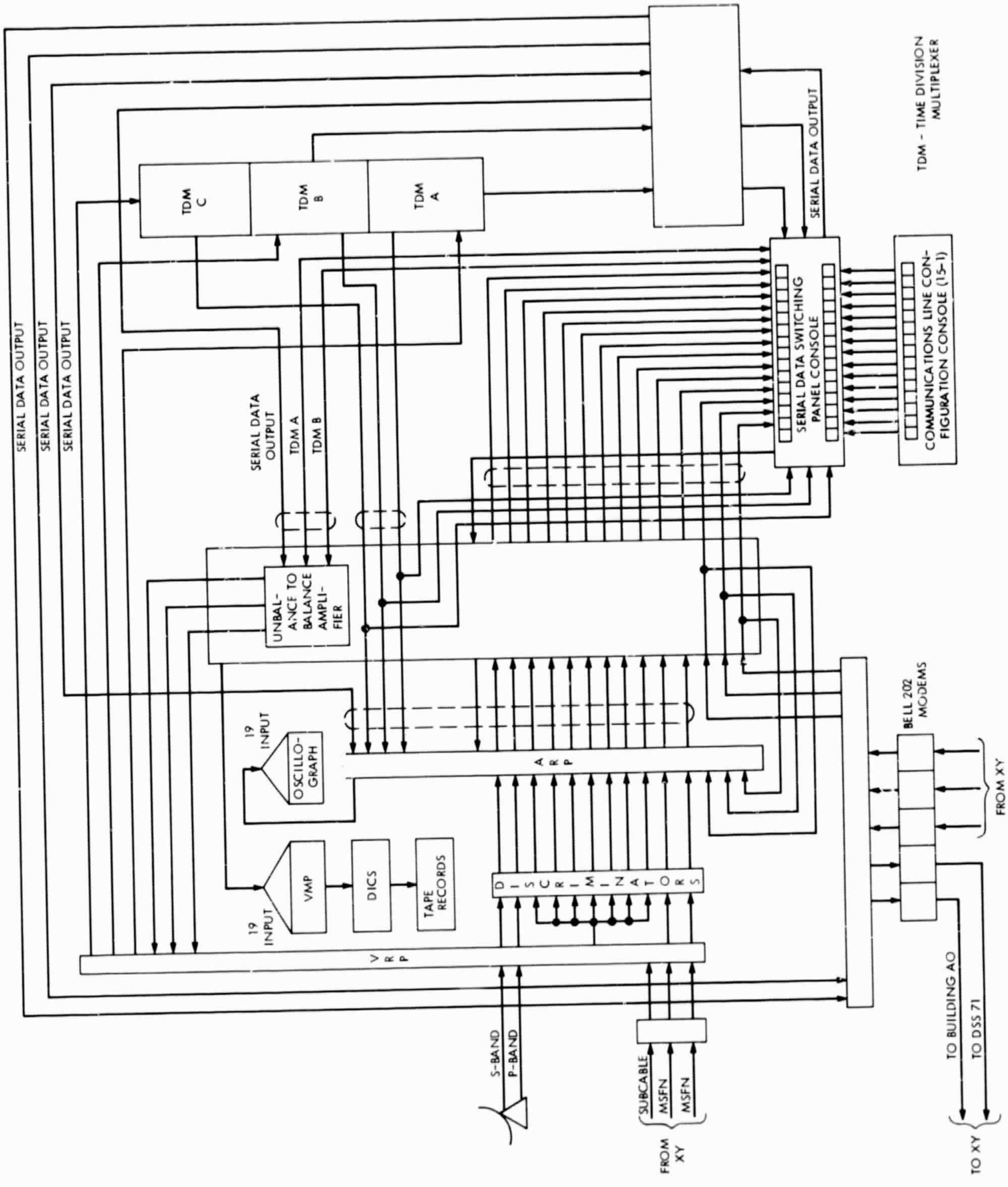


Fig. 45. AFETR serial data routing and switching system

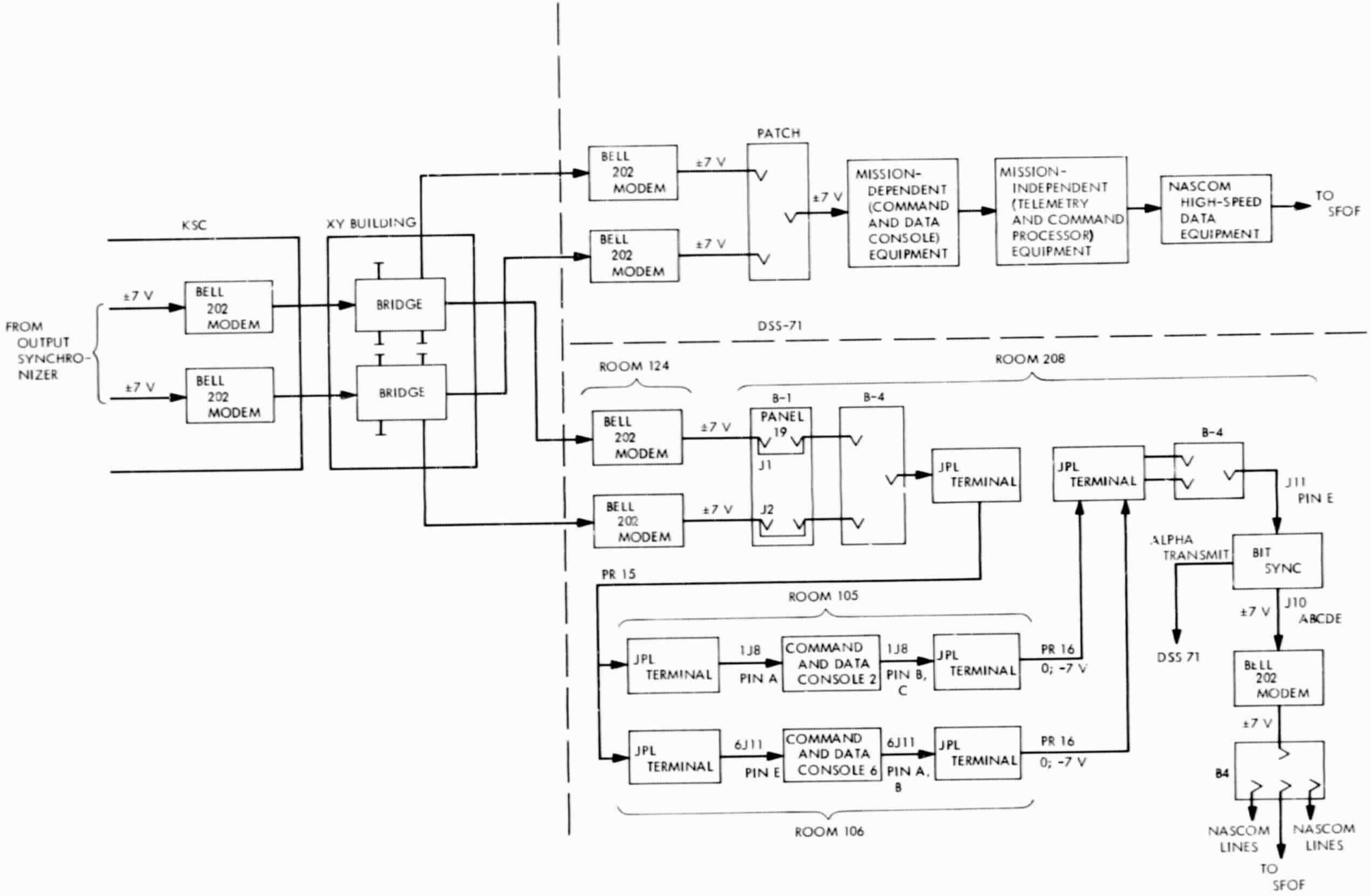


Fig. 46. Telemetry data distribution/building AO—DSS 71

All requirements were met. The VHF telemetry data, including spacecraft data, were transmitted in real-time to the SFOF from liftoff to spacecraft High-Power-On. At High-Power-On AFETR switched, as planned, to real-time transmission of spacecraft S-band telemetry data. Real-time data flow was of excellent quality. The HF propagation conditions were such that the retransmission of data was not hampered by communication conditions.

Retransmission coverage is shown in Fig. 47.

c. Real-time computer system. The RTCS provided all required support for *Surveyor VII.* The following computations were made from AFETR, MSFN, *Centaur* guidance telemetry, and DSN data.

A parking orbit was computed using Antigua free flight data. The solution was considered good and agreed closely with the nominal. Interrange vector, standard orbital parameter message, and orbital elements were provided from this solution.

A theoretical transfer orbit was computed, using the above solution plus nominal second burn data. An interrange vector, standard orbital parameter message, orbital elements, and look angles for Tananarive and Carnarvon were provided. Deep Space Network predicts for DSSs 51 and 42 were also provided. The system data analysis group indicated that these predicts agreed closely with the nominal predicts.

An initial transfer orbit was computed, using about 3 min of Pretoria data. This solution was considered a good fit by the RTCS, and an interrange vector, standard orbital parameter message, and orbital elements were provided from this computation. Updated look angles for Carnarvon and DSN predicts for DSS 42 were also provided. The system data analysis group indicated these predicts agreed closely with the nominal predicts for

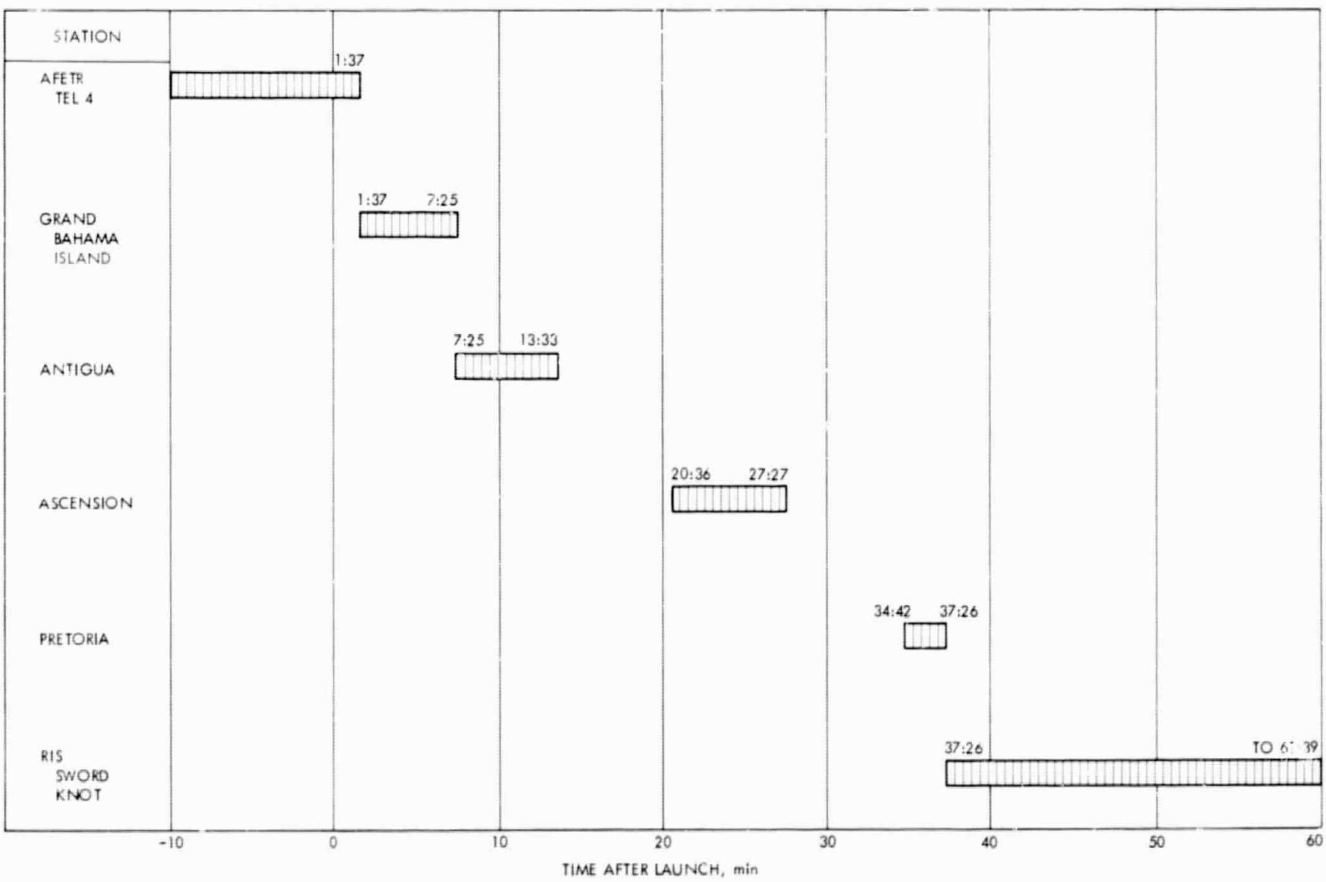


Fig. 47. Real-time retransmission of spacecraft telemetry data

the transfer orbit. The RTCS also provided moon mapping (in the **B**-plane) and an **I**-matrix from this computation.

Tables 35–37 show the orbit generation, computations and initial lunar encounter predicts produced by the RTCS.

2. ***Manned Space Flight Network.*** The MSFN, managed by GSFC, supported the *Surveyor VII* Mission by performing the following functions:

(1) Tracking of the *Centaur* beacon (C-band).

(2) Receiving and recording *Centaur*-link telemetry.

(3) Receiving, recording and retransmitting S-band telemetry to DSS 42 in real-time.

(4) Providing real-time confirmation of certain *mark* events.

(5) Providing computing support through the use of GSFC data operations branch.

(6) Providing NASCOM support to all NASA elements for simulations and launch, and extending this communications support as necessary to interface with the combined worldwide network.

a. Tracking (C-band). Figure 48 gives the MSFN radar coverage support provided for the *Surveyor VII* Mission.

Because of noisy paramp Klystron thermostat, FPQ-6 was operated in the paramp bypass mode. Bermuda reported FPQ-6 had excellent pass, achieving 426 s of valid auto-track data. The FPS-16 tracked passively, obtaining 295 s of track data.

Table 35. Real-time computer system orbit generation for *Surveyor VII*

Orbit	Epoch, s	Time of computation, s	Data source	Quality
Centaur/spacecraft parking orbit	676	900	Antigua	Good
Predicted Centaur/ spacecraft transfer orbit	2049	1190	Antigua plus nominal second burn	Good
Preretro transfer orbit	2123	2520	Pretoria (3 min)	Good
Centaur postretro orbit	2819	3420	Carnarvon (7 min)	Good
Centaur/spacecraft parking orbit	674	3660	Guidance telemetry	—
Preretro transfer orbit	2162	5220	Pretoria (free flight data only)	Poor
Centaur/spacecraft parking orbit	673	6000	Antigua telemetry via KSC	Good
Actual spacecraft transfer orbit	4813	8400	DSS 42	Good

Table 36. Real-time computer system orbit computation for *Surveyor VII*

Orbit	Data source	Epoch,[a] GMT	Semimajor axis, km	Inclination, deg	Eccentricity, deg	C_3,[b] km^2/s^2
Parking	Antigua	06:41:16.9	6542.5	30.692	0.00061	−60.92
Parking	Guidance telemetry	06:41:15.3	6545.3	30.688	0.00076	−60.89
Parking	Antigua telemetry via KSC	06:41:14.2	6543.4	30.686	0.00046	−60.91
Theoretical	Antigua plus second burn	07:04:09.5	361,320.3	30.687	0.98188	−01.10
Preretro	Pretoria (3 min)	07:05:24.0	355,366.6	30.691	0.98158	−01.12
Preretro	Pretoria (free flight)	07:06:03.0	329,368.3	30.693	0.98012	−01.21
Postretro	Carnarvon (7 min)	07:17:00.0	230,247.5	30.685	0.97157	−01.73
Actual transfer	DSS 42	07:50:17.0	361,236.8	30.663	0.98187	−01.10

[a]Epoch is for Jan 7, 1968.
[b]C_3, twice the energy per unit mass.

Table 37. Initial lunar encounter predictions for *Surveyor VII*

Orbit mapped	Data source	B,[a] km	B • T,[b] km	B • R,[c] km	Time of closest approach (1/10/68), GMT
RTCS transfer orbit	Pretoria	2,947.3	2,926.5	349.4	01:39:48.4
RTCS postretro (*Centaur*)	Carnarvon	24,427.0	24,403.0	1,075.9	13:19:15.0
RTCS DSN spacecraft orbit based on DSS 42 data	DSS 42	1,927.0	1,847.3	551.1	01:00:54.2
SFOF transfer orbit (radar data)	Pretoria	2,040.0	1,993.36	433.7	00:58:08.1
SFOF first spacecraft orbit based on DSN data	DSS 42	2,077.9	2,009.1	530.6	01:01:11.1
Final SFOF solution used for midcourse maneuver	DSS 42 DSS 51 DSS 61	2,075.4	2,044.1	359.0	01:02:53.5

[a]**B**, magnitude of the impact parameter.
[b]**B** • **T**, projecton of the impact parameter **B** upon the vector **T**.
[c]**B** • **R**, projection of the impact parameter **B** upon the vector **R**.

Tananarive provided valid data during an overall interval of 458 s.

Tananarive had loss of track at 07:12:58 GMT, and reacquired at 07:14:13 GMT. The first AOS occurred at 07:11:59, first LOS at 07:12:58, reacquired at 07:14:13 GMT. Final LOS 07:19:35 GMT. Good signals were reported.

Carnarvon reported beacon exceptionally good during view periods. Experienced abrupt LOS preceded by heavy lobing. Loss of track at 07:27:54 and reacquired at 07:34:24 GMT. Carnarvon first AOS occurred at 07:14:12, first LOS at 07:27:54, reacquired at 07:34:24, and final LOS at 07:48:06 GMT. Initial tracking interval provided 822 s of valid data, and another 822 s of data were obtained after the dropout.

b. Telemetry (VHF). Figure 49 gives the MSFN telemetry coverage provided for *Surveyor VII.*

Carnarvon reported a 1-min telemetry dropout caused by interference from the local airport equipment.

Computer coverage extended to 04:05:00 GMT only, but Carnarvon would have had much longer coverage if there had been such a requirement.

The DSS 42 reported using Carnarvon data from 07:13:13 to 07:27:18 GMT only. The remainder of their track was as backup to DSS 42.

Carnarvon was given release at 07:50:45 GMT.

c. Computer. During launch the prepass acquisition messages generated by GSFC data operations branch were in error, but those transmitted during the pass were excellent.

All other support was provided as required.

Bermuda covered *mark* events 5, 6, 7, 8, and 9. The Bermuda actual AOS time was 06:33:55 and LOS time was 06:40:58 GMT.

Tananarive covered *mark* events 22, 24, 25, and 26, but was unable to confirm *mark* event 23. Tananarive actual AOS time was 07:05:30 and LOS time was 07:25:10 GMT. Real-time data transmission to hangar AE included *Centaur* yaw rate, roll rate, and spacecraft separation. Tananarive had a serial decimal time problem during launch that produced an erroneous day indication.

Carnarvon covered *mark* events 25 and 26.

Carnarvon actual AOS time was 07:13:45, and LOS time was 08:03:54 GMT.

The actual coverage for Tananarive and Carnarvon significantly exceeded the estimated coverage. This is valid for Tananarive, because of equipment modifications which improve the range, but is unrealistic for Carnarvon. The latter part of this station's actual coverage comprised bad data.

d. NASCOM support. The NASCOM network provided teletype, voice, and high-speed data circuits in

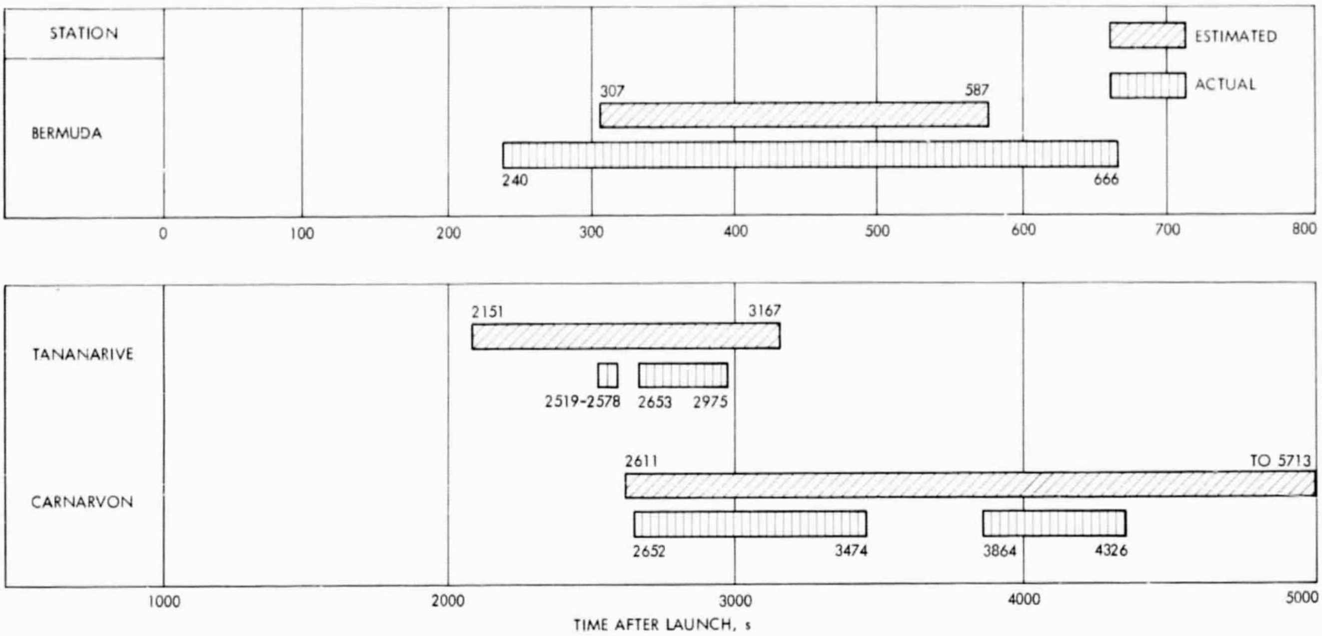


Fig. 48. Manned Space Flight Network radar coverage

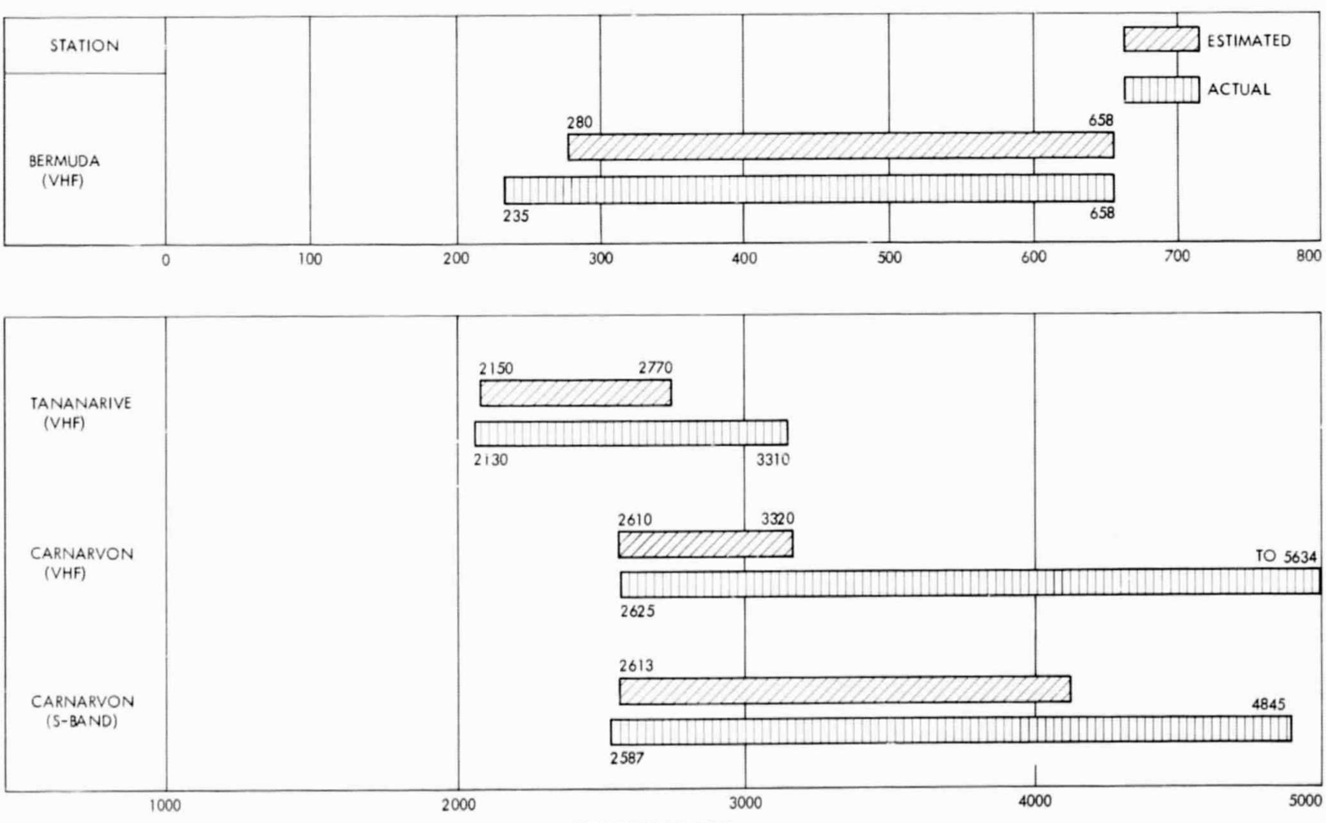


Fig. 49. Manned Space Flight Network telemetry coverage

support of *Surveyor VII*. The circuits were assigned as indicated below.

Site	No. of circuits		
	TTY	Voice	High-speed data
Building AO	3	3	1
DSS 71	3	1	1
DSS 42	4	1	1
DSS 51	3	2	1
DSS 61	4	1	1
Carnarvon/ DSS 42	—	1	1
Ascension/ Cape Kennedy	1	—	1
Ascension/ JPL	—	—	1

Special coverage was established commencing at approximately $T - 7\frac{1}{2}$ h, and special propagation forecasts were provided for HF radio circuits effective at $T - 9\frac{1}{2}$ h.

One TTY and one voice circuit were activated from DSS 51 via Pretoria, Ascension, and communication satellite to GSFC to JPL. Quality of the teletype circuit was excellent during the time when other DSS 51 circuits were lost. The voice circuit via this route was marginal, but usable.

The DSS 51 high-speed data circuit was not of sufficient quality to provide acquisition support. Instead, DSS 51 average alarm and tracking data were transmitted to JPL via TTY. All circuits to DSS 51 suffered periodic outages, commencing at about $T - 4$ h and continuing through liftoff.

With the exception of the high-speed data and voice circuits and the two TTY circuits to DSS 51, the NASCOM network was green at liftoff. The DSS 51 voice and teletype circuits were restored prior to DSS 51 rise.

Excellent quality was maintained on both the TTY and voice/data circuits that were routed from Ascension to Cape Kennedy and JPL via the communication satellite.

3. Near-earth phase performance evaluation. The combined AFETR and MSFN TDS coverage summary is illustrated in Fig. 50. As can be seen, the actual coverage exceeds the estimates in most cases.

The project and the individual data users agreed that the TDS support provided for this mission was the best to date. The lack of operational problems, as compared to past missions, was noted; it was considered that the TDS, as an integrated whole, performed excellently.

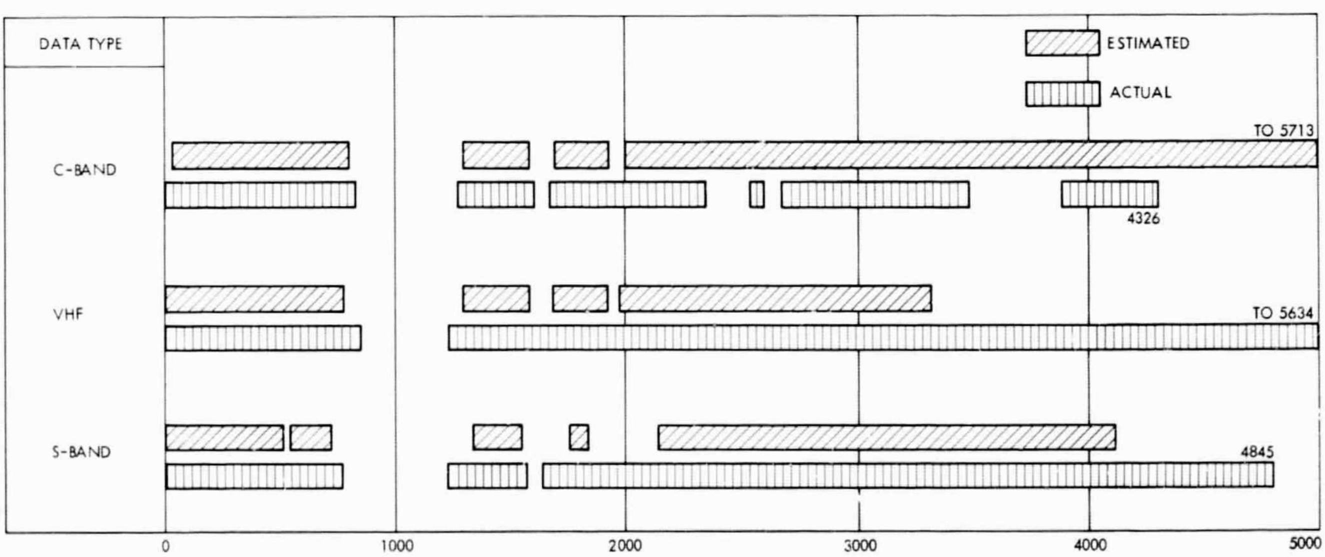


Fig. 50. Combined AFETR and MSFN TDS coverage summary

The TDS near-earth phase network included selected resources of the AFETR, the MSFN, the DSN, and NASCOM. Coverage was provided for *Atlas/Centaur* tracking data (metric), *Atlas/Centaur* telemetry (VHF), *Surveyor* telemetry (VHF and S-band), and real-time orbit computation. The TDS support for the mission was considered good and the minor problems experienced had no significant effect on the overall support. All requirements were met and, in most cases, exceeded. An option was exercised to extend the 60-min hold at $T - 90$ min by an additional 35 min, thus ensuring near-optimum tracking coverage by downrange stations.

Tracking data acquisition during the near-earth phase was good, and all class I requirements were met. The mainland stations, Grand Bahama Island, Grand Turk, and Antigua provided continuous coverage from liftoff to $T + 808$ s. Ascension covered the interval from $T + 1286$ to $T + 1592$ s, and RIS *Twin Falls* and Pretoria provided coverage from $T + 1670$ to $T + 2342$ s. A short dropout occurred as predicted during the Grand Turk interval.

Atlas/Centaur telemetry coverage via VHF was greater than predicted and all requirements were met or exceeded. Continuous and substantially redundant VHF telemetry was received beginning with the countdown, through Antigua LOS at $T + 826$ s, and from $T + 1225$ to $T + 3261$ s. All *mark* events except 19 and 23 were received and read out by AFETR and MSFN stations.

Spacecraft S-band telemetry was received continuously from liftoff to $T + 760$ s by KSC, Grand Bahama Island, and Antigua. With the exception of a short gap between Ascension and RIS *Twin Falls*, these two stations, Pretoria, and RIS *Sword Knot* provided continuous coverage from $T + 1225$ to $T + 3709$ s.

All requirements for real-time transmission of *Surveyor* telemetry data to the SFOF were met. As planned, data via VHF was provided from liftoff to spacecraft High-Power On, and thereafter via S-band.

The RTCS provided all required support. A total of eight orbits were computed by the RTCS, including a parking orbit using Antigua data, a second and third parking orbit using *Centaur* guidance telemetry data, a theoretical transfer orbit using Antigua data plus nominal second burn data, two actual preretro transfer orbits from Pretoria data, a postretro orbit using Carnarvon data, and a spacecraft orbit from DSS 42 data. From these, interrange vector, orbital elements, MSFN look angles, DSN predicts, moon-mapping and injection matrices were provided.

B. Deep Space Network Phase

As with the *Surveyor VI* Mission the DSN provided a constant high level support for *Surveyor VII*, with the exception of that listed below.

The DSS 71 received spacecraft telemetry from prior to launch to $T + 6$ min, 2 s. The signal strength was nominal, confirming a good spacecraft transmitter at launch, as shown in Fig. 51.

The prime data source for transmission of AFETR real-time telemetry from KSC to the SFOF was via the command and data console (CDC) and telemetry and command processor computer at DSS 71, with the Bell 202 dataphone circuit as backup. This link provided excellent high-speed data at the SFOF.

The Carnarvon-to-DSS 42 link delivered good data to the SFOF from DSS 42 decommutator lock (on Carnarvon data) at 07:13:12 GMT until the telemetry processing station changed over to processing DSS 42 data at 07:28:34 GMT.

The DSS 51 acquired the spacecraft of 07:04:53 GMT and tracked in the on-way mode until 07:08:38. The DSS 42 acquired at 07:20:25 GMT, which marked the beginning of continuous DSN view. The DSS 72 was not activated for this mission.

At 06:52:50 GMT, DSS 51 and DSS 42 predicts were reported leaving AFETR and arrived at the stations in time for acquisition. In view of the problems existing at the same time in the JPL/communication processor interface which could have prevented JPL predicts getting to the stations, the timely arrival of AFETR predicts was significant.

From the time of two-way acquisition by DSS 42 until approximately retroignition -40 min, the DSN tracked *Surveyor VII* in the two-way mode and, with minor exceptions, returned extremely high quality, two-way doppler data. *Surveyor VI* marked the first use of doppler resolver data during the inflight portion of a *Surveyor* mission; for *Surveyor VII*, all participating stations were equipped with doppler resolvers and the data were, of course, used in flight. The result of using the doppler resolver was a reduction in the standard deviation of the

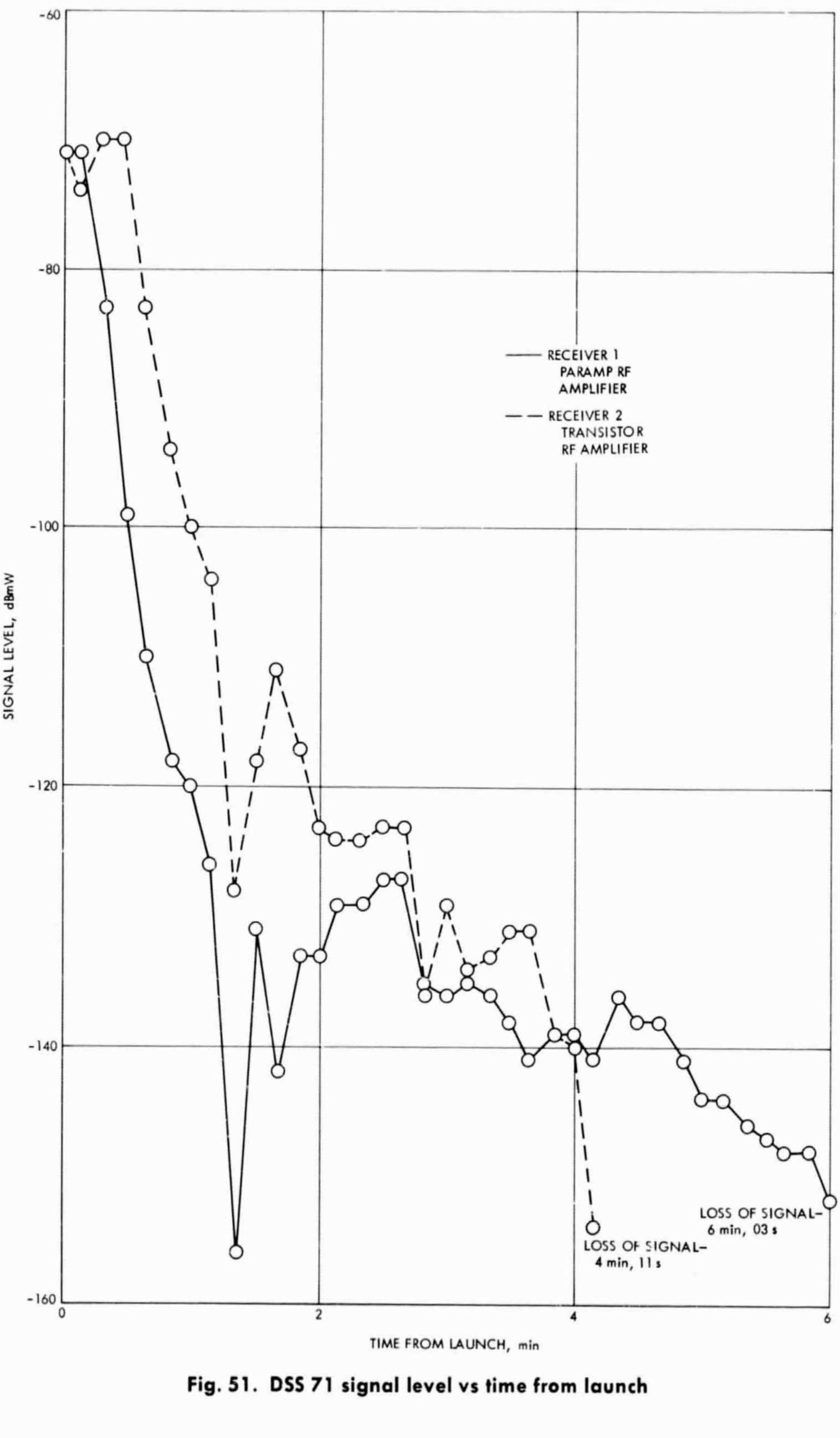


Fig. 51. DSS 71 signal level vs time from launch

doppler data (60-s samples) from a preresolver level of approximately 0.008 to about 0.002 Hz, or a reduction by a factor of 4. Unfortunately, this did not produce a significant decrease in the corresponding target uncertainties because, at doppler resolver levels, the main component of the target uncertainties is computer noise and not data noise. The only significant losses of good two-way doppler data occurred during the first passes over DSSs 51 and 11. Approximately ½ h of good two-way doppler data at the start of its first pass were lost by DSS 51 because of a faulty frequency shifter unit; the problem was eliminated by replacing the unit. The DSS 11 lost 30 min of doppler resolver data during the midcourse maneuver (although the basic two-way doppler data was not affected) due to a misadjusted potentiometer in the doppler resolver counter, the problem was eliminated by correctly adjusting the potentiometer (however, DSS 14 made the same error on its third pass).

The DSN tracking data and alpha scattering data recovery was good throughout the mission, with very little real-time data lost. Data losses were caused, primarily, by minor GCF problems which occurred during the operational periods.

1. Deep Space Instrumentation Facility. The following Deep Space Stations were committed as prime stations for support of the *Surveyor VII* Mission:

DSS	Name
11	Goldstone Deep Space Communications Complex, Barstow, Calif.
42	Tidbinbilla, Australia, near Canberra
61	Robledo, Spain, near Madrid

In addition to the basic support provided by prime stations, the following support was provided for the *Surveyor VII* Mission:

(1) DSS 71, Cape Kennedy, provided facilities for spacecraft/DSIF compatibility testing, and also received and recorded telemetry data after liftoff. In addition, DSS 71 used its CDC and telemetry and command processor computer to process AFETR range telemetry data for transmission to JPL.

(2) DSS 14 Mars, Goldstone Deep Space Communications Complex, Barstow, Calif., provided backup tracking and command support during midcourse and terminal maneuvers, using its 210-ft-diam antenna. At touchdown, the baseband telemetry output of the DSS 14 prime receiver was transmitted to the SFOF.

(3) DSS 51, Johannesburg, South Africa, provided tracking support during the transit phase.

For the January 7, 1968 launch date, DSS 42 was designated the initial two-way acquisition station as it met all the acquisition criteria of both the DSIF and the *Surveyor* Project.

Approximately 46 min after lunar touchdown DSS 11 commanded and received 200-line TV pictures. On January 10, during the spacecraft's fourth pass over DSS 61, the ASI was commanded to the background data position and received the first alpha scattering experiment data.

DSS 11 commanded the ASI to be lowered to the lunar surface during the spacecraft's fourth pass over DSS 11; however, the instrument failed to lower because of a malfunctioning escapement mechanism. During the fifth pass over DSS 11, the surface sampler was successfully commanded to push the ASI to the lunar surface.

Starting on January 13, 1968, the DSIF provided tracking support during a series of laser experiments. From January 15 through 17, 1968, the DSIF supported two unsuccessful attempts to revive *Surveyors I, III, V,* and *VI* spacecraft. For the remainder of the first lunar day the DSIF provided spacecraft operations support by commanding soil sampler, alpha scattering experiment, and TV picture sequences, as well as receiving and recording the following types of data: lunar rock bearing, TV meteorological pictures of the earth, magnet study, polarmetric survey and rock polarization studies, star survey, alpha scattering experiment studies, laser beam experiment, and multipath tests.

One-way spacecraft signals were received by DSS 71 for 6 min and 3 s after liftoff. Signal levels received varied from approximately −68 dBmW on the pad at liftoff to −158 dBmW at loss of signal. Also, DSS 71 processed real-time AFETR telemetry with its CDC and on-site telemetry and command processor computer.

DSS 51 acquired spacecraft signals 34 min after launch and tracked the spacecraft for 3 min and 45 s during the first pass. The DSS 51 provided support during all three of its transit-view periods.

The initial two-way acquisition was achieved by DSS 42, 7 min and 58 s after spacecraft rise over the stations horizon. Slightly over 8 min elapsed from the receipt of the first spacecraft signals until DSS 42 was prepared to command the spacecraft. Signal levels varied from approximately −128 dBmW at first RF contact to −88 dBmW at the time commanding began.

From the time of initial two-way acquisition by DSS 42 until approximately 40 min before spacecraft main retroignition, Deep Space Stations tracked *Surveyor VII* in the two-way mode, and, with minor exceptions, received high-quality doppler data. For *Surveyor VII* all participating stations were equipped with doppler resolvers, which resulted in a reduction in the standard deviation of the doppler data by a factor of 4. However, this did not produce a significant decrease in the corresponding target uncertainties because at doppler resolver levels the main component of the target uncertainties was computer noise and not data noise.

The midcourse maneuver was successfully commanded by DSS 11 during its first pass. Two midcourse adjustments were scheduled but orbit calculations indicated that the first midcourse performed the necessary adjustments, hence the second midcourse was not required. DSS 14 also provided support during the midcourse maneuver using its 210-ft antenna.

The spacecraft terminal maneuvers and retrodescent were successfully commanded during the third DSS 11 pass. A smooth spacecraft touchdown in the targeted area was achieved with no loss of receiver lock at the three stations having spacecraft visibility (DSSs 11, 14, and 61).

The signal levels received at the Deep Space Stations during the transit phase are shown in Fig. 52 and correspond very closely to the predicted levels. The predicted levels for the prestar acquisition track are not given as the spacecraft was not roll-stabilized during this period. Therefore, the received signal level could vary over a wide range because of variations in spacecraft antenna patterns. During star acquisition, midcourse correction, and retromaneuver, the spacecraft was in high-power mode and the received data were 16.5 dB above the low-power signal level. Data bit rate changes occurred within 2 dB of the predicted thresholds. The periods during which gyro drift tests were conducted are shown at the top of the illustrations. The random gyro drift and subsequent antenna pattern variations produced a spread in the received signal level of ±3 dB.

At touchdown, the baseband telemetry output of the DSS 14 prime receiver was transmitted to the SFOF using the wideband microwave line. The DSS 14 provided excellent support during all of its tracking periods.

After the lunar landing, the DSIF provided 24-h/day tracking coverage, with DSSs 11, 42, and 61 providing postlanding mission operations support.

During lunar operations, several losses of uplink lock were experienced by both DSSs 11 and 42, with a consequent loss of command capability. In each case uplink was reacquired and commanding proceeded normally.

The DSIF provided essentially continuous support to *Surveyor VII* during all spacecraft operating periods. Prime station support was provided by DSSs 11, 42, and 61; DSS 51 provided additional support during all three of its transit-phase view periods. Initial two-way acquisition and commanding of the spacecraft was performed by DSS 42. DSS 71 supported the prelaunch spacecraft–DSIF RF compatibility tests, and, during the launch phase, was the prime source of real-time AFETR telemetry transmission to the SFOF. The DSS 14 provided transit phase and lunar operations support using the 210-ft antenna.

During lunar operations there were instances of loss of uplink lock and consequent loss of command capability. In each case, the uplink was reacquired and commanding proceeded normally. This occurred at DSSs 11, 61, and 42 on different occasions. The DSIF participated fully in investigating these problems but no evidence of ground equipment malfunctions could be found.

During prelaunch preparations, there was momentary concern over the readiness of the TV ground data handling system at Goldstone (TV-11) for mission support. The main problems were due to extended mission support provided to *Surveyors V* and *VI* during December, the tight schedule, and the amount of testing required prior to the *Surveyor VII* Mission. With the help and cooperation of TV-1 personnel, all tests were completed and TV-11 performed efficiently and reliably throughout the first lunar day.

Various operational, equipment, and interface problems were experienced during the mission; however, none caused a serious loss of data or had any significant effect on the overall mission.

The following is a summary of the major activities of each station during the mission.

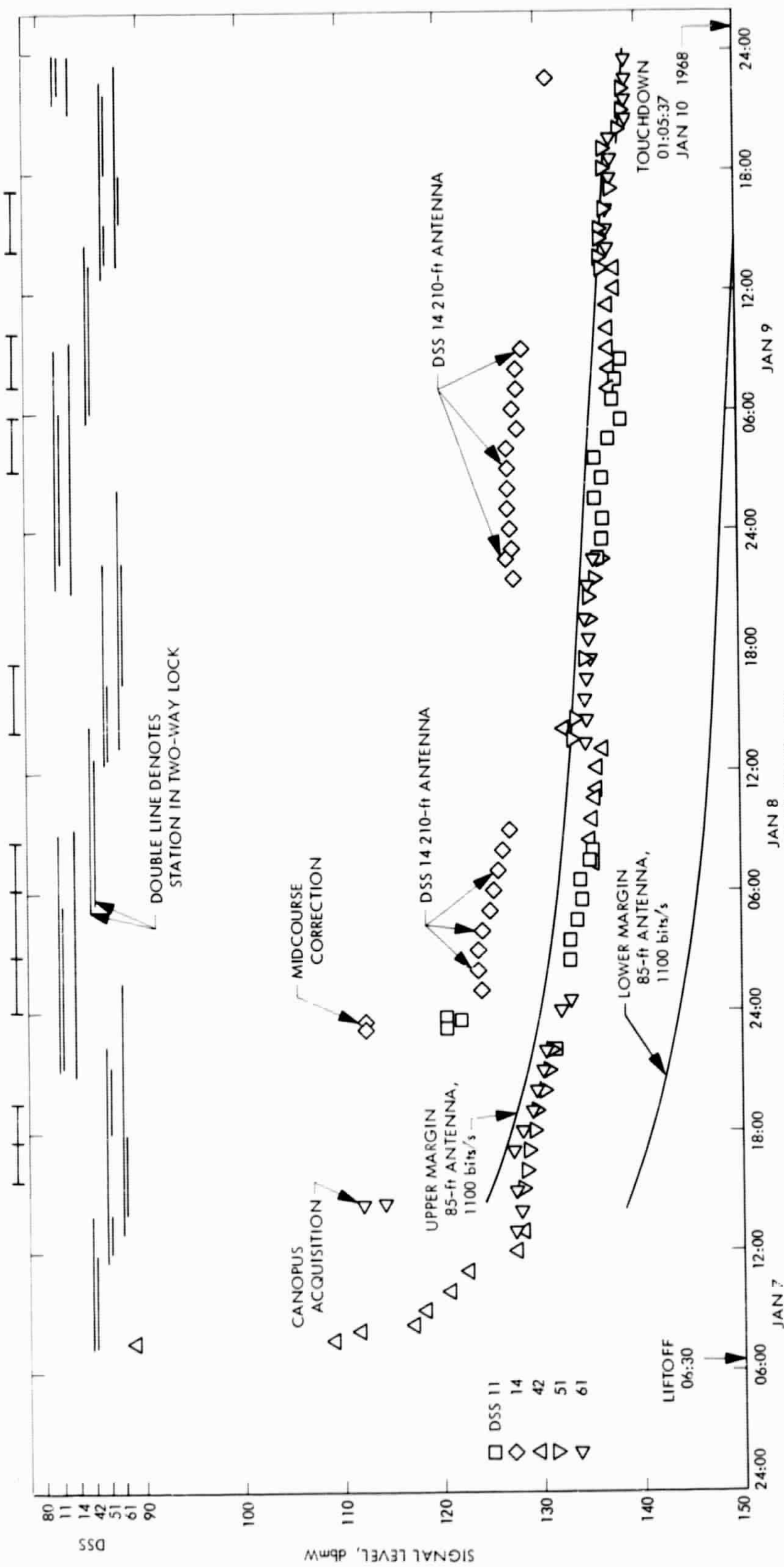


Fig. 52. Deep Space Station-received signal level

a. DSS 11—Goldstone (Pioneer) Calif. The DSS 11 tracked *Surveyor VII* for three passes during the transit phase, commanding the critical midcourse and terminal maneuvers. After the touchdown pass, DSS 11 continued tracking during the remainder of the lunar day and into the lunar night, compiling a total of 16 passes. During the first pass on day 7–8, the midcourse maneuver was commanded with nominal performance except for star lockon which was performed manually due to sensor saturation. The terminal descent sequence was successfully commanded on the third pass with nominal spacecraft response. A modified postlanding sequence was accomplished and the first 200-line TV frame was received within 45 min after touchdown. The A/SPP positioning was accomplished after fourteen 200-line frames were received, and the remainder of the third pass was devoted to 600-line TV and engineering interrogations. Station activity on subsequent passes emphasized SM/SS operations and TV pictures. The surface sampler was utilized to deploy the ASI after the normal deployment mechanism failed, and to move the instrument to two other locations on the lunar surface. Alpha scattering data were acquired and engineering interrogations were performed throughout the lunar operational period. In addition, the station participated in the laser experiments and an RF multipath experiment. Several unsuccessful attempts were made to revive other *Surveyor* spacecraft when *Surveyor VII* was in standby.

Several operational and equipment problems were encountered; however, none resulted in any serious effect on the mission.

b. DSS 14—Goldstone (Mars), Calif. The DSS 14 with its 210-ft antenna provided transit phase support during all three passes. Provision had been made to allow the DSS 11 CDC to utilize the DSS 14 receiver output, if necessary. Project-furnished equipment was installed to permit predetection recording. At midcourse and touchdown, the baseband telemetry receiver output was transmitted to the SFOF via the microwave link. Good data were received from DSS 14 during all three tracking periods.

c. DSS 42—Tidbinbilla (Canberra) Australia. During the transit phase of the mission, DSS 42 had three tracking periods and performed the initial two-way acquisition and spacecraft commanding. Good PCM data were received from Carnarvon prior to DSS 42 first view. These data were processed and transmitted to the SFOF for approximately 14 min before switching to DSS 42 data after acquisition. After touchdown, DSS 42 continued to track for 16 passes during the lunar day and into the lunar night. During the lunar passes, the station was quite active with extensive TV operations, alpha scattering data acquisitions, A/SPP positioning, RF and signal processing experiments, engineering interrogations, and power/thermal management activities.

Although several operational and equipment problems were encountered, none had any significant effect on the mission.

d. DSS 51—Johannesburg, South Africa. The DSS 51 acquired on the launch pass after injection and tracked the spacecraft for approximately 4 min during a very short view period. Although communications were poor, the station was able to verify that the spacecraft status was nominal and that automatic solar panel deployment was taking place. During the three succeeding transit phase passes, DSS 51 tracked both two- and three-way, monitored the star acquisition performed by DSS 61, and performed engineering interrogations and gyro drift checks. Some decoder switching was observed during the third pass. Except for the loss of approximately 30 min of two-way data during the first pass because of a faulty frequency shifter unit, no significant equipment or operational problems were encountered which adversely affected the mission.

e. DSS 61—Madrid, Spain. The DSS 61 tracked the spacecraft for three passes during the transit phase and for 16 passes during the lunar phase. Star acquisition was performed on the first transit pass. During the roll maneuver, automatic star lockon did not function properly and it was necessary to perform a manual lockon. Except for the star acquisition sequence, commanding from DSS 61 was minimal during the transit passes. However, the station was in view during midcourse and touchdown and these events were monitored until the end of the view. Activities during the lunar day and night consisted of extensive television, alpha scattering accumulations, engineering interrogations, A/SPP positioning and power/thermal management. Sunset at the spacecraft occurred earlier than anticipated during DSS 61 view, and the station successfully obtained shadow progression and solar corona TV sequences. During one pass, a period of high winds caused noise spikes in the RF system and forced a change in bit rate from 1100 bits/s for both telemetry and alpha scattering data. The immediate source of this problem was not determined. Several other operational and equipment problems were encountered; none had any significant effect on the mission, however.

f. DSS 71—Cape Kennedy, Fla. The DSS 71 support for the mission consisted of providing PCM data to the SFOF during the spacecraft prelaunch countdown and up through the end of the near-earth phase. Source of the data was building AO until $T-5$ min and KSC thereafter until approximately $T+40$ min. Data in both cases were processed by the CDC and the telemetry and command processor computer and transmitted to the SFOF via high-speed data line and TTY. This data path worked quite well and good data were received at the SFOF during all times that good data were received.

2. *Deep Space Network/GCF.* For *Surveyor* missions, the GCF transmits tracking, telemetry, and command data from the DSIF to the SFOF, and control and command functions from the SFOF to the DSIF by means of NASCOM facilities. The GCF also transmits simulated tracking data to the DSIF and video data and baseband telemetry from DSS 11, Goldstone Deep Space Communications Complex, to the SFOF. On the *Surveyor VII* Mission all communication circuits between the DSIF and SFOF were automatically switched using a communication processor.

In general, the NASCOM network provided excellent support throughout the mission. Communications processor operations proved reliable during critical mission phases. During lunar operations, the Goddard communications processor experienced a number of failures but these did not cause serious loss of data. Hardwire teletype circuits were available in the event of a communications processor failure during critical periods, but were not needed during the mission.

Two new earth satellite communications circuits were made available to the AFETR Ascension Island station to provide improved downrange communications reliability. One satellite circuit consisted of a dataphone circuit from AFETR station 12 to JPL via GSFC. Good data were received in the telemetry processing station via this circuit; however, the data were not processed because of the high-quality data received via the normal KSC/DSS 71 path. A second satellite circuit was used to transmit downrange metric teletype data from Ascension to Cape Kennedy; this circuit also provided good data. The Goldstone microwave circuits, including the 6-MHz video line, performed very well during the mission. One significant 6-MHz line problem occurred, causing loss of real-time data for part of one pass. All data were recovered at the end of the pass, and the prime data recorded at DSS 11 were not affected.

Special communications support linking all participating stations was provided for the laser experiment.

a. Teletype circuits. Teletype circuits (four available to prime stations) are used for transmitting tracking and telemetry data, commands, and administrative traffic. The *Surveyor VII* Mission was supported through the Canberra, London, Goddard, and JPL communication processor.

At launch the communications processor/data processing system interface could not be established but was restored 1 min after launch and caused no data loss. The communications processor proved very reliable during critical mission phases. Hardwire teletype circuits were available in the event of a processor failure. These circuits were checked out during premission testing, but they were not needed during the transit phase of the flight because of the high reliability of the processors during this period. During lunar operations the project did not elect to use the hardwire circuits because of the generally short duration of the processor outages that did occur. During lunar operations Goddard and overseas processors experienced many periodic outages, which did not, however, cause a serious loss of data.

Teletype communications through this system were considered excellent. During lunar operations there were 22 failures at Goddard, necessitating manual and automatic recoveries and some system swaps; however, their effects were minimal. The Canberra communications processor experienced three failures and London processor experienced five; all were of short duration.

Utilization of the communications processor system, however, did not exempt DSS 51 from propagation-caused outages. Teletype communications during the *Surveyor VII* Mission were nevertheless degraded because of this continuing problem.

The teletype circuits and the processor were exceptionally reliable; the weakest circuits (to DDS 51) showed approximately 97% reliability.

b. Voice circuits. The voice circuits are shared between the DSIF and the *Surveyor* Project for administrative control and commanding functions. The NASCOM voice circuits provided for the *Surveyor VII* Mission performed well except for several minor outages.

The voice portion of the NASCOM network generally provides a higher reliability factor than the TTY, with the exception of the radio link between London and Pretoria. Similar to the DSS 51 teletype circuits, degraded propagation conditions caused the majority of voice failures to South Africa. The DSS 51 voice was out at launch due to propagation, but was restored prior to acquisition. The balance of the NASCOM voice circuits encountered very little outage time, and when outages did occur, they were held to short durations by means of switching to alternate make-good circuits. Voice communications with the Goldstone stations was nearly optimum and no major problems were encountered.

All voice circuits exhibited 99–100% reliability except DSS 51, the weakest circuit, which showed 95% reliability.

c. High-speed data lines. One high-speed data line is provided to each prime site for telemetry data transmission to the SFOF in real-time. This part of the communications system performed well during both the prelaunch testing and mission phases.

The outbound sides of the lines were used during testing to transmit simulation data to the stations and during the mission to backfeed various voice nets as required. During the mission all high-speed data lines exhibited from 99 to 100% reliability except DSS 51, which showed 91% reliability, as it experienced outage during the initial short launch pass due to propagation. Both NASCOM and Hallicrafter data sets (DSS 51 only) were employed for *Surveyor VII* and no major problems were encountered at any of the DSN stations.

d. Wideband microwave system. The wideband microwave link between DSS 11, Goldstone Deep Space Communications Complex, and the SFOF consists of one 6-MHz simplex (one-way) channel for video, and one 96-kHz duplex (two-way) data channel.

Communications between JPL and Goldstone via the Western Union microwave system was almost 100% reliable in passing TTY, voice, and high-speed data. However, that portion of the microwave system that carries the 6-MHz video channels did experience one outage of 23 min during the *Surveyor VII* Mission. This outage was due to a high B-beam pilot tone, causing the beam to switch to oscillate sooner than normal. Other system failures were minor, and of short duration. Longer outages on the system were avoided by immediate switching to the backup landline circuits.

e. Television ground data handling system. The system used for the *Surveyor VII* Mission was the same as the configuration used during the *Surveyor VI* Mission.

Operations in the TV-1 area were comparatively smooth and trouble-free during the entire lunar day. Real-time spacecraft signals received via the microwave link from DSS 11 were of excellent quality with the exception of a portion of one view period when microwave channel switching problems occurred. The lost data were recovered on the following day from the DSS 11 FR-900 recording.

When possible, minor equipment failures within the TV-1 area were corrected in real-time and TV data losses were held to a minimum. Among these failures were:

(1) The main clutch spring in film transport 1 broke but was rebuilt and installed by JPL machinists with minimum loss of film data transfer.

(2) The video data simulator used during countdown calibrations failed to operate in the framing mode. The TV-11 simulator was employed as a backup and countdown calibration schedules were met.

(3) Normal wear to photo processing equipment gear trains and drive belts required replacement in real-time during operations but did not affect photo product delivery schedules.

During the first lunar day, TV-1 recovered a total of 20,993 video frames via microwave from TV-11 and from FR-800 tapes recorded overseas. From these, the following photo products were produced:

Type	Quantity
Mosaic	648 negatives, 1134 prints
Photo enlargement	5619 prints
Strip contact print	560 rolls
Master positive	80 rolls
Public Information Office duplicate	80 rolls
Engineering data record	80 rolls
Command and data console film	59 rolls
Video tapes recorded at TV-1:	
HW-7600 analog recorder	90 each
FR-1400 analog recorder	26 each
FR-700 video recorder	68 each

f. Deep Space Network/AFETR interface. The DSN/AFETR interface provides real-time data transmission capability for both VHF and S-band downrange telemetry from building AO at Cape Kennedy to the SFOF. The nominal switchover time from VHF to S-band data is after the spacecraft S-band transmitter high-power turnon. Incoming AFETR telemetry is sent from KSC simultaneously to building AO and to DSS 71 for processing and transmission to JPL. The output of both stations is transmitted to the SFOF via the GCF/NASCOM. During the *Surveyor VII* Mission, the KSC to DSS 71 configuration was established as the prime link between the SFOF and AFETR to provide an interface similar to the data transmission links with prime Deep Space Stations. The previously used link between building AO and SFOF, via Bell modems, was retained as backup.

In addition, two new satellite communications circuits were used from the Ascension Island station of AFETR to provide improved reliability of communications from down range. These circuits were implemented by NASCOM in cooperation with AFETR. One voice/data grade circuit extended from AFETR station 12 (Ascension) to JPL via GSFC. A total of 202 data sets were used to transmit 550 bits/s *Surveyor* data direct to JPL from Ascension and stations farther down range. Good data were received in telemetry processing stations via this circuit; however, it was not processed because of the high quality of the data coming in via the normal KSC/DSS 71 path. A second satellite circuit was used to transmit downrange metric data via teletype from Ascension to Cape Kennedy. This circuit was also checked out and provided good data.

Inflight spacecraft telemetry was received from the AFETR stations and relayed to the SFOF until approximately 40 min after liftoff.

Both the prime DSS 71 and the building AO backup circuits provided good data during the mission, but due to the high quality of the DSS 71 data, the building AO data were not processed. The backup system was also used during the ORT to provide simulated telemetry data from the SFOF to building AO and performed well.

The DSIF tracking data for early orbit determination was successfully backfed to the real-time computer system at the AFETR.

The system for transmission of real-time telemetry data from the Carnarvon, Australia MSFN station to the SFOF via DSS 42 was again activated for *Surveyor VII*. This system performed very well and good data was received in the SFOF from Carnarvon acquisition until DSS 42 switched over to processing their own data, a period of approximately 14 min.

3. *Deep Space Network/SFOF.* The DSN supports *Surveyor* missions by providing mission control facilities and performing special functions within the SFOF.

a. Data processing system. The SFOF Data Processing System performs the following functions for *Surveyor* missions:

(1) Computation of acquisition predictions for DSIF stations (antenna pointing angles and receiver and transmitter frequencies).

(2) Orbit determinations.

(3) Maneuver computation and analysis.

(4) On-line telemetry processing.

(5) Command tape generation.

(6) Simulated data generation (telemetry and tracking data for tests).

The data processing system general configuration for *Surveyor* missions consisted of two PDP-7 computers in the telemetry processing station, two strings of IBM 7044/7094 computers in the central computing complex and a subset of the input/output system.

The IBM 7044/7094 redesign software system, modified to process both *Mariner IV* and *Surveyor VII* data, was utilized in the data processing system during the *Surveyor VII* Mission. Teletype traffic, other than *Surveyor*, was not removed from the communications processor during the critical periods as had been done on the *Surveyor V* and *VI* Missions. Manning of the data processing system was adequate and the performance of all personnel was skillful and proficient.

Significant differences from prior missions were:

(1) The IBM 7044W and IBM 7094V were reconfigured as a mode 2 string and closed-circuit monitors were installed.

(2) Computer program MTGS was modified to increase the accuracy in some of the constants.

(3) Coordination procedures were modified in order to speed up the initiation of predict transmissions.

(4) The NASCOM end-of-message marks and new headers were generated by the IBM 7044 every 15 min or every 5400 teletype characters, whichever occurred sooner.

The following problems deserving special attention were encountered:

(1) At liftoff, the interface between 7044X and the communications processor failed, causing incomplete words to be received by the 7044. The computer programs were loaded on the Y-string as expeditiously as possible and operations continued on the Y-string.

(2) During the midcourse maneuver, telemetry processing station 2 faulted, causing a momentary loss of data until the program was restarted. PDP-7 3 was replaced by PDP-7 1, but the faults recurred to the extent that station 2 operations were significantly curtailed during lunar operations.

(3) During the terminal phase, the 7044W queue list could not be cleared. The 7094 also indicated disk transmission errors. The telemetry processing was switched to the Y-string. This resulted in orbit determination program card read problems. The 7044X was then made available and was used to process telemetry data during the terminal descent.

(4) Communication processor computer changes induced interface problems between the processor and the 7044, necessitating several restarts of the 7044.

(5) The orbit determination program did not run successfully when telemetry data were being processed by the same string. It is suspected that the problem may be due to a card read problem in the 7044/7094 program.

(6) The organizational interfaces between mission-dependent and mission-independent personnel in the SFOF computer operations became extremely awkward and drawn-out at times. These interfaces should be better defined and well understood.

Surveyor VII utilized a redesigned computer configuration in conjunction with a communication processing system which automatically switched teletype lines and allowed computer sharing in support of other concurrent space program missions. Its capabilities included switching, real-time monitoring, quick-access message logging and recall. Communication processor problems, although not significantly affecting the mission, did cause minor delays in providing SFOF user areas with incoming data.

The data processing system performed in an excellent manner, with only minor hardware problems that did not detract from mission support. The two PDP-7 computers were used extensively to process high-speed telemetry data for the *Surveyor VII* Mission. This processing consisted of decommutating and transferring the data to the 7044 computer via the 7288 data channels, generating a digital tape for non-real-time processing, and supplying digital-to-analog converters with discrete data parameters to drive analog recorders in both the spacecraft analysis area and the space science analysis area.

The IBM 7044/7094 computer string dual configuration successfully processed all high-speed data received from the telemetry processing station and all teletype data received from the communications center, as well as all input/output requests from the user areas.

The input/output system provides the capability for entering data control parameters into the 7044/7094 computers and also for displaying computed data in the user areas via the various display devices. The input/output system performed adequately; many minor problems were reported, but were resolved in real-time with only a minor loss of data.

b. Deep Space Network/ICS. The DSN/ICS provides the capability of receiving, switching, and distributing all types of information required for spaceflight operations and data analysis to designated areas or users within the SFOF. The system includes facilities for handling all voice communications, closed circuit TV, TTY, high-speed data, and data received over the microwave channels.

The DSN/ICS performed in an exceptional manner, with only minor anomalies.

Both modem* types (NASCOM and Hallicrafters) were required during the *Surveyor VII* Mission. The NASCOM modems were used for sending high-speed data from all stations except DSS 51, and reliability was very high. The DSS 51 used the Hallicrafters modems, which performed reliably; the only circuit problems were caused by propagation. Minor problems occurred during launch

*A modem (modulator–demodulator) is a device for converting a digital signal to a signal which is compatible with telephone line transmission (e.g., frequency-modulated tone).

when several stations were active and modem switching was required within the SFOF so that each station could perform data transfer tests.

The TV communications subsystem experienced minor equipment problems that were resolved in real-time. During the launch phase there was a shortage of TV monitors used for viewing teletype lines.

c. Evaluation. The overall performance of the maintenance and operations personnel and equipment in the SFOF in supporting the *Surveyor VII* Mission was satisfactory. Staffing for the mission was adequate, and no manning problems were experienced in any of the operation and support areas.

Major changes in the facility between the *Surveyor VI* and *VII* Missions were:

(1) The 7044W and 7094V computers were reconfigured into a new operational W-string.

(2) The new SFOF computer-driven display system was used and a number of interesting and useful displays were developed to support real-time operations.

A significant problem in the interface between the communications processor and 7044X occurred shortly before liftoff. As discussed above, the Y-string was brought up as a replacement for the X-string. The net result was a 15-min loss of the CP/7044 at a critical time during the countdown.

Another significant problem occurred on January 18, 1968 when a circuit breaker controlling the diesel power unit was switched off in error. This resulted in a shutdown of some communications equipment in the SFOF, and caused a 25-min delay in providing data to the project.

C. Tracking Data Analysis

The *Surveyor VII* spacecraft was tracked by prime *Surveyor* DSIF stations at Johannesburg, South Africa (DSS 51), Canberra, Australia (DSS 42), Madrid, Spain (DSS 61), and Goldstone, Calif. (DSS 11), and by backup station DSS 14 at Goldstone, Calif., from shortly after transfer orbit injection until lunar touchdown at 01:05:28 GMT on January 10, 1968. The DSIF then continued to track the spacecraft on the lunar surface until 14:14:00 GMT on January 26, 1968, or approximately 80 h into the lunar night. Actual station tracking periods during the inflight portion of the mission, together with nominal view periods, may be seen in Table 38.

1. Spacecraft center frequencies. So that spacecraft predictions may be generated and supplied to the DSN tracking stations for purposes of spacecraft acquisition, aided track, and station-to-station transfers of the spacecraft, it is essential that the spacecraft transmitter (one-way) center frequencies and transponder (two-way) center frequencies be accurately known. The nominal values for these frequencies are 2295.000000 MHz (at carrier level) for the transmitter center frequency and

Table 38. Nominal view periods vs actual tracking at Deep Space Stations

Date	DSS	Nominal rise, GMT	Nominal set, GMT	Nominal view period[a]	Acquisition by station, GMT	Loss of signal by station, GMT	Actual view period
Jan 7	51	07:03:01	07:07:11	00:04:10	07:05:06	07:08:36	00:03:30
	42	07:20:04	13:37:08	06:17:04	07:22:12	13:35:02	06:12:50
	51	11:33:52	22:19:33	10:45:41	11.33:02	22:24:02	10:51:00
	61	13:00:15	01:35:53	12:35:38	12:59:02	01:33:02	12:34:00
	11	21:06:54	09:02:10	11:55:16	21:07:02	08:56:02	11:49:00
Jan 8	42	05:06:43	14:18:59	09:12:16	05:15:02	14:18:02	09:03:00
	51	12:32:48	22:34:30	10:01:42	12:32:02	22:24:02	09:52:00
	61	13:16:47	02:08:48	12:52:01	13:18:02	02:06:02	12:48:02
	11	21:19:37	09:17:05	11:57:28	21:27:02	09:11:02	11:44:00
Jan 9	42	05:27:52	14:26:39	08:58:47	05:30:02	14:28:02	08:58:00
	51	12:44:38	22:37:33	09:52:55	13:20:02	22:39:02	09:19:00
	61	13:18:44	02:21:26	13:02:42	13:33:02	02:20:54	12:47:52
	11	21:25:41	09:34:21	12:08:40	21:34:02	09:37:00	12:02:58

[a]Based on horizon mask for all stations except DSS 72, which is based on 0-deg elevation.

22.013670 MHz (at station VCO level) for the transponder center frequency. These frequencies are measured months before the mission for use in the preflight prediction document, and again measured several times within the last 10 h of the countdown for use in real-time predictions. The frequencies which were used in the preflight prediction document were:

Frequency, MHz	Transmitter/transponder
2294.990100	Transmitter A at 110°F
2294.990100	Transmitter B at 110°F
22.013672	Transponder A at 90°F
22.013615	Transponder B at 90°F

These frequencies were abstracted from preflight data supplied by HAC. During the countdown, frequency measurements were made and sent to the SFOF at $T - 669$, 565, 326, 50, 30, and 20 min, approximately as called for in the sequence of events. These measurements were plotted against the preflight frequency vs temperature curves and can be seen in Figs. 53–56. In previous *Surveyor* missions (*III–V*) the preflight data were biased by the countdown frequency measurements for use during the actual flight. For *Surveyor VI*, a 60-Hz bias was added to the preflight transponder frequency vs temperature curves in an effort to more accurately predict inflight frequencies. However, since neither of these methods has effectively achieved the desired result, the preflight curves were used unaltered. Real-time frequency predictions were obtained by using the preflight vs temperature curves in conjunction with real-time temperature predictions; these values are shown in Table 39. The various transmitter B one-way frequencies reduced from the one-way data recorded during *Surveyor VII* are presented in Table 40; these values can be compared to the data presented in Figs. 53 and 54.

2. ***Spacecraft predictions.*** Spacecraft predictions, which are composed of time-tagged observables such as antenna pointing angles, one-, two-, and three-way doppler, best-lock ground transmitter frequency, etc., are routinely provided to the DSN tracking stations to insure the success of spacecraft acquisition, aided track, and station handovers of the spacecraft. However, during the launch phase, the provision of accurate predictions to DSSs 51 and 42 becomes a critical matter because of the crucial need for early acquisition and commanding of the spacecraft. For first two-way acquisition at DSSs 51 and 42, there are three distinct sets of predictions available:

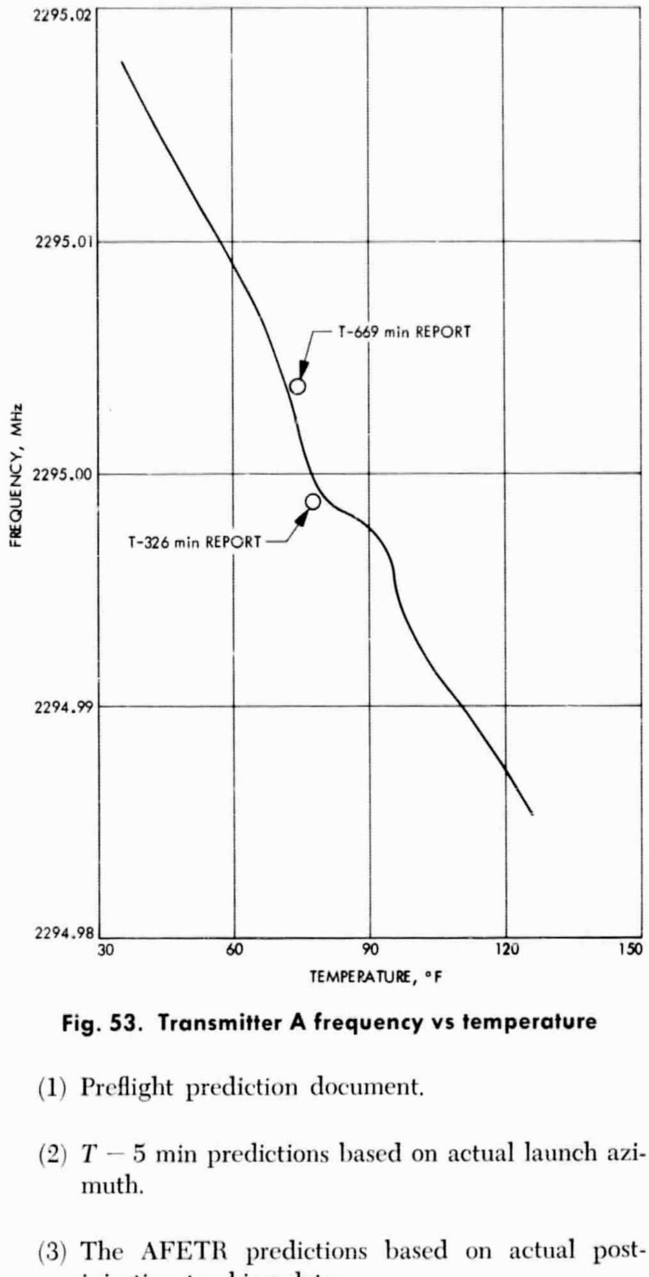


Fig. 53. Transmitter A frequency vs temperature

(1) Preflight prediction document.

(2) $T - 5$ min predictions based on actual launch azimuth.

(3) The AFETR predictions based on actual post-injection tracking data.

Although both the preflight predictions and the $T - 5$ min predictions are generated before launch, the $T - 5$ min predictions have two important advantages over the preflight predictions in that they are based on updated frequency information and are generated for the exact actual launch azimuth. For these reasons, the $T - 5$ min predictions were generated and sent to DSSs 51 and 42 with the instruction that they be used instead of the preflight prediction document. A minor communication

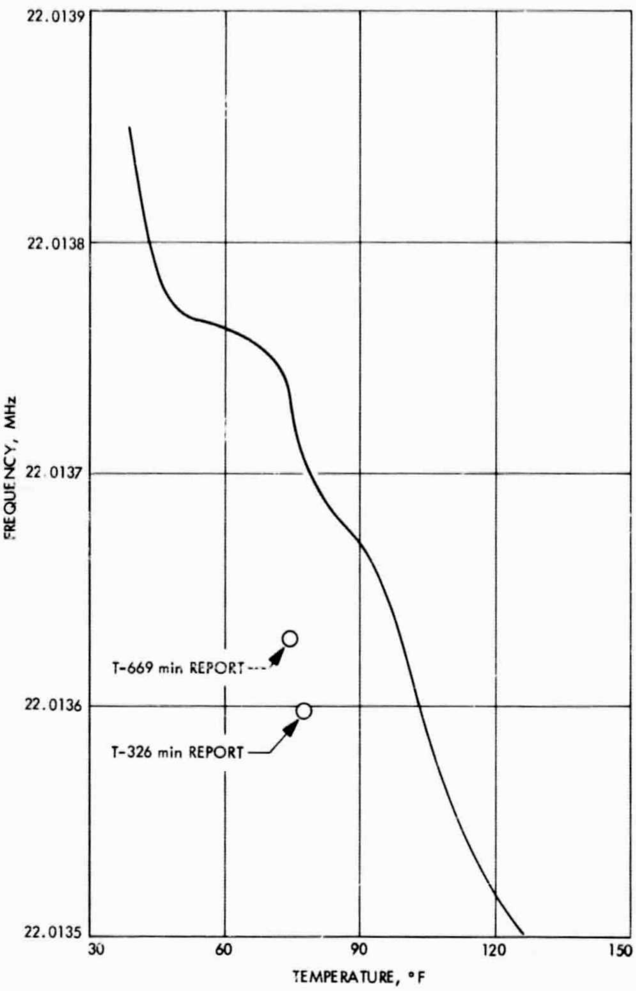


Fig. 54. Transponder A frequency vs temperature

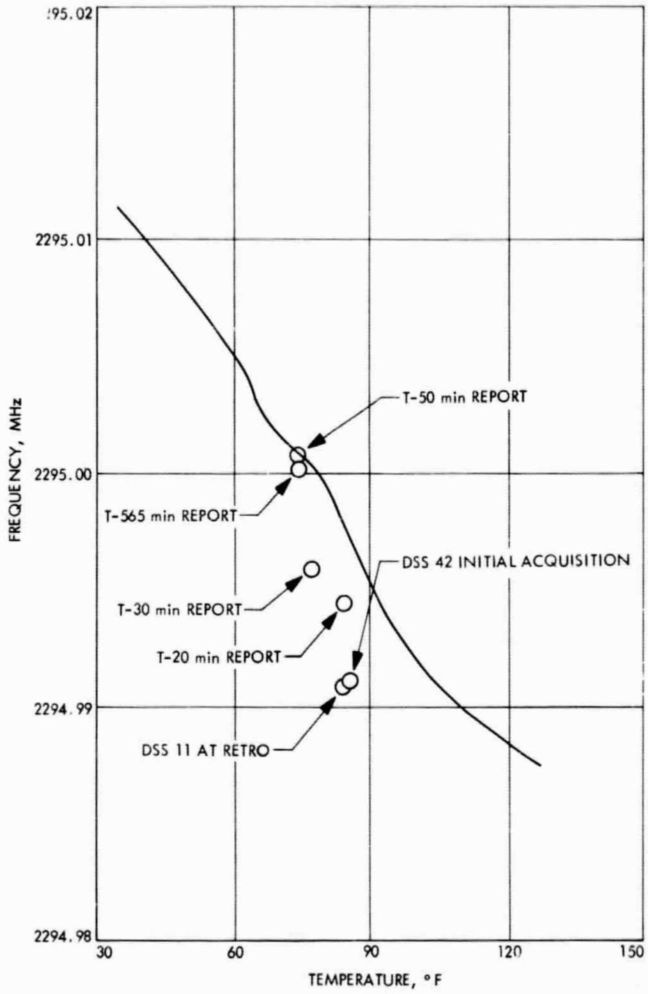


Fig. 55. Transmitter B frequency vs temperature

processor failure at approximately launch time delayed the $T - 5$ min predicts by about 10 min. Both stations reported receipt of the $T - 5$ min predicts at about $T + 15$ min and DSS 51 subsequently acquired the spacecraft in the one-way mode using these predicts. At $T + 22$ min, AFETR predicts based on a nominal second burn arrived, and at $T + 45$ min, AFETR predicts based on the actual transfer orbit arrived, both sets verifying the accuracy of the $T - 5$ min predicts. Using the $T - 5$ min predicts, DSS 43 performed the initial two-way acquisition in a nominal fashion. It should be noted that the AFETR predicts arrived quite quickly (in contrast to the sluggish AFETR predict performance in the *Surveyors V* and *VI* Missions) such that they would have been quite useful had they been needed. During the remainder of the mission, predictions were routinely supplied to all participating DSIF stations.

3. Initial two-way acquisition at DSS 42. Predictions indicated a *Surveyor VII* rise at DSS 42 at 07:20:04 GMT on January 7, 1968, or $T + 50$ min 05 s. DSS 42 received good, one-way data at 07:20:25 (rise + 00:21) GMT, reported auto-track on the acquisition aid antenna at 07:23:00 (rise + 02:56) GMT, auto-track on the antenna main beam shortly thereafter, and good two-way data at 07:28:02 (rise + 07:58) GMT.

This acceptable but relatively slow two-way acquisition time can be partially attributed to the comparatively slow ascent of the spacecraft above the horizon. Acquisition procedure prohibits turning on the transmitter prior to a 10-deg elevation over the local horizon. This can account for as much as 2 min in this type of acquisition. Taking this factor into consideration, the acquisition compares reasonably with past missions.

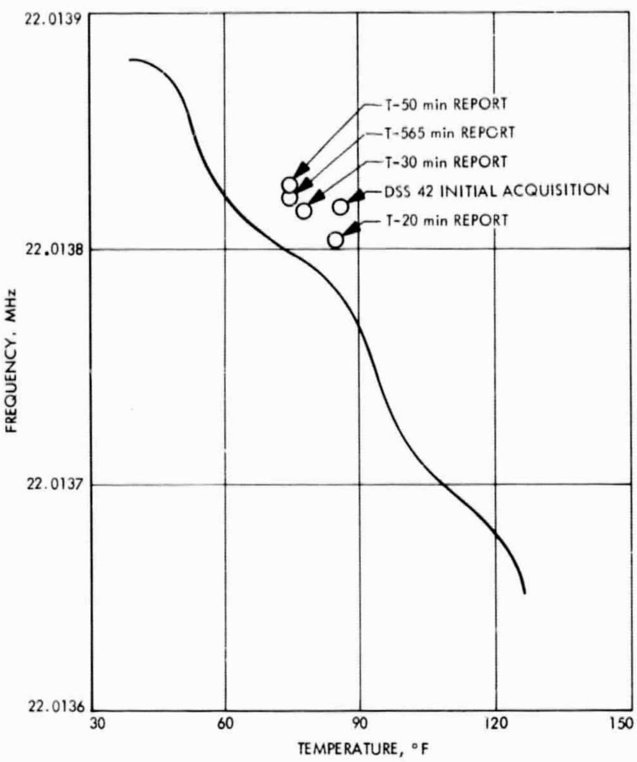


Fig. 56. Transponder B frequency vs temperature

4. Tracking performance. The DSN provided continuous angular and doppler tracking of the inflight portion of the *Surveyor VII* spacecraft from initial one-way acquisition at DSS 42 at 07:20:25 GMT on January 7, 1968 through lunar touchdown at 01:05:28 GMT on January 10.

In general, the overall quality of the tracking data taken during the *Surveyor VII* Mission can be described as excellent. Data types used in the orbit determination program were angular data taken during the first pass of DSS 42 and two-way doppler data taken during all passes of DSSs 61, 51, 42, and 11.

A summary of these data, together with statistics, is given in Table 41. The relative quality of the tracking data taken at each station can be obtained by comparing the standard deviations, the root-mean-squares, and the first moments of the data as listed in the table. Changes in the quality of the same data as reflected in different orbits are largely attributable to the particular selection criteria of each orbit as determined by the orbit determination group.

Table 39. *Surveyor VII* frequency prediction

Time after launch, h	Temperature, °F	Frequency, MHz
	Transmitter B[a]	
L–16	85	2294.994178
16–42	60	2295.005600
42–50	54	2295.010800
50–*R*	74	2295.002000
	Transponder B[a]	
L–16	85	22.013798
16–42	60	22.013824
42–50	54	22.013838
50–*R*	74	22.013800
Time after retroignition, days	Temperature, °F	Frequency, MHz
	Transmitter A[b]	
R–3	88	2294.998000
3–8	110	2294.993000
8–13	80	2294.999109
13–17	50	2295.012900
17–21	20	2295.021500
	Transponder A[b]	
R–3	88	22.013676
3–8	110	22.013625
8–13	80	22.013698
13–17	50	22.013771
17–21	20	22.013855

[a]Used in flight.
[b]Used after touchdown.

Orbit identifications are as follows:

Orbit	Identification
Predict	PROR
Injection condition evaluation	ICEV
Preliminary premidcourse	PREL
Data consistency	DACO
Nominal midcourse	NOMA
Last premidcourse	LAPM
Premidcourse cleanup	PRCL
Postflight analysis	POST
N^{th} postmidcourse	N POM
Final inflight	FINAL

In general, DSIF station operations during the *Surveyor VII* Mission were effectively implemented. This is best judged by the fact that the DSN was able

Table 40. Auxiliary oscillator frequency reduced from one-way doppler data

DSS	Pass	Day	Time, GMT	Auxiliary oscillator frequency, MHz
51	0	07	07:05:11	2294.994556
			07:05:21	2294.994790
			07:05:31	2294.993987
			07:05:41	2294.994031
			07:05:51	2294.993761
			07:06:01	2294.993769
			07:06:11	2294.993652
			07:06:21	2294.993649
			07:06:31	2294.993588
			07:06:41	2294.993584
			07:06:51	2294.993545
			07:07:01	2294.993539
			07:07:11	2294.993520
42	1	07	07:21:27	2294.992238
			07:21:37	2294.992210
			07:21:47	2294.992178
			07:21:57	2294.992149
			07:22:07	2294.992118
			07:22:17	2294.992089
			07:22:27	2294.992057
			07:22:37	2294.992028
			07:22:47	2294.991997
			07:24:47	2294.991644
61	1	07	14:23:32	2294.998888
			14:24:32	2294.998872
			14:25:32	2294.998849
			14:26:32	2294.998822
			14:27:32	2294.998784
			14:28:32	2294.998738
			14:29:32	2294.998682
			14:30:32	2294.998621
			14:31:32	2294.998555
			14:32:32	2294.998479
			14:33:32	2294.998398
			14:34:32	2294.998314
			14:35:32	2294.998223
			14:36:32	2294.998128
			14:37:32	2294.998027
61	1	07	14:38:32	2294.997923
			14:39:32	2294.997816
			14:40:32	2294.997705
			14:41:32	2294.997590
			14:42:32	2294.997474
			14:43:32	2294.997356
			14:44:32	2294.997233
			14:45:32	2294.997108
			14:46:32	2294.996983
			14:47:32	2294.996855
			14:48:32	2294.996725
			14:49:32	2294.996592
61	3	10	00:23:32	2294.995595
			00:24:32	2294.995490
			00:25:32	2294.995392
			00:26:32	2294.995299
			00:27:32	2294.995199
			00:28:32	2294.995094
			00:29:32	2294.994983
			00:30:32	2294.994874
			00:31:32	2294.994765
			00:32:32	2294.994649
			00:33:32	2294.994530
			00:34:32	2294.994406
			00:35:32	2294.994286
			00:36:32	2294.994169
			00:37:32	2294.994047
			00:38:32	2294.993919
			00:39:32	2294.993787
			00:40:31	2294.993664
			00:40:41	2294.993644
			00:40:51	2294.993622
61	3	10	00:41:01	2294.993603
			00:41:11	2294.993582
			00:41:21	2294.993563
11	3	09	23:05:32	2294.996911

to provide very high quality data to the orbit determination group such that they were able to meet all orbital accuracy requirements for such events as the midcourse maneuvers, retromotor ignition backup, etc. From the time of first two-way acquisition of the spacecraft over DSS 42 until shortly before retroignition, the spacecraft was almost continuously in two-way lock, and station transfers were rapidly and effectively executed. The only major losses of good two-way doppler data occurred during the first passes over DSS 51 and DSS 11. The DSS 51 lost approximately one-half hour of good two-way doppler at the start of their first pass due to a faulty frequency shifter unit; the problem was eliminated by replacing the unit. The DSS 11 lost 30 min of doppler resolver data during the time of midcourse maneuver (although the basic two-way doppler data was not effected) due to a misadjusted potentiometer in the doppler resolver counter; the problem was eliminated by correctly adjusting the potentiometer (however, DSS 14 made the same error on the third pass). The effect from these data losses on the mission was negligible.

a. Premidcourse phase.

Angular tracking. In general, doppler data yield far greater accuracy in the determination of a spacecraft orbit than do angular data and are, therefore, used almost exclusively in the orbit determination process during most of the mission.

Table 41. Summary of premaneuver DSS tracking data used in *Surveyor VII* orbit computations

Orbit identification	DSS	Data type	Beginning data time, mo/day—GMT	End data time, mo/day—GMT	No. of points	Standard deviation	rms	Mean error	Remarks
PROR YA	42	CC3	1/07—07:28:07	1/07—07:45:17	99	0.0129	0.0129	0.000326	Data from DSS 42 between 07:28 and 07:29 GMT were 10-s sample rate; all other premidcourse DSS data were 60-s sample rate
		HA	1/07—07:28:02	1/07—07:45:22	96	0.00559	0.00559	−0.0000383	
		dec	1/07—07:28:02	1/07—07:45:22	96	0.00456	0.00457	−0.000219	
PROR WA	42	CC3	1/07—07:28:07	1/07—08:23:32	202	0.0901	0.123	0.0844	
		HA	1/07—07:28:02	1/07—08:24:02	204	0.0609	0.0609	−0.000306	
		dec	1/07—07:28:02	1/07—08:24:02	204	0.0311	0.0311	−0.000360	
ICEV YA	42	CC3	1/07—07:28:07	1/07—08:41:32	212	0.0173	0.0175	0.00210	
		HA	1/07—07:28:02	1/07—08:42:02	219	0.00703	0.00744	−0.00245	
		dec	1/07—07:28:02	1/07—08:42:02	219	0.0132	0.0140	−0.00465	
ICEV WA	42	CC3	1/07—07:28:07	1/07—08:55:32	226	0.0181	0.0182	0.00145	
		HA	1/07—07:28:02	1/07—08:56:02	233	0.00896	0.00951	−0.00317	
		dec	1/07—07:28:02	1/07—08:56:02	233	0.0143	0.0154	−0.00572	
PREL YA	42	CC3	1/07—07:28:07	1/07—09:36:32	265	0.00490	0.00490	−0.0000313	
PREL WA	42	CC3	1/07—07:28:07	1/07—09:33:32	262	0.00499	0.00499	−0.000171	
PREL WB	42	CC3	1/07—07:28:07	1/07—10:32:32	321	0.00456	0.00456	−0.0002	
DACO YB	42	CC3	1/07—07:28:07	1/07—11:54:32	399	0.00480	0.00480	−0.0000355	
	51	CC3	1/07—12:22:32	1/07—13:54:32	80	0.00210	0.00214	0.000421	
DACO WC	42	CC3	1/07—07:28:17	1/07—11:54:32	398	0.00503	0.00504	0.000290	
	51	CC3	1/07—12:22:32	1/07—13:53:32	76	0.00396	0.00421	0.00143	
	61	CC3	1/07—14:56:32	1/07—16:30:32	91	0.00646	0.00646	−0.000335	
NOMA YA	42	CC3	1/07—07:28:07	1/07—11:54:32	399	0.00431	0.00432	−0.000222	DSS 51 data
	61	CC3	1/07—12:22:32	1/07—17:32:32	167	0.00321	0.0032[illegible]	−0.0000672	
NOMA WA	42	CC3	1/07—07:28:07	1/07—11:54:32	339	0.00724	0.00724	0.000122	
	51	CC3	1/07—12:22:32	1/07—13:53:32	76	0.00238	0.00616	0.00568	
	61	CC3	1/07—14:03:32	1/07—17:53:32	188	0.00907	0.00908	−0.000234	
NOMA WB	42	CC3	1/07—07:28:07	1/07—11:54:32	399	0.00463	0.00463	0.0000612	
	51	CC3	1/07—12:22:32	1/07—13:53:32	76	0.00269	0.00276	0.000630	
	51	CC3	1/07—18:03:32	1/07—18:31:32	19	0.00251	0.00269	0.000977	
NOMA YC	42	CC3	1/07—07:28:07	1/07—11:54:32	399	0.00418	0.00419	−0.00296	
	51	CC3	1/07—12:22:32	1/07—13:53:32	80	0.00324	0.00325	0.000177	
	51	CC3	1/07—18:03:32	1/07—18:50:32	28	0.00235	0.00255	−0.000944	
	61	CC3	1/07—14:03:32	1/07—17:53:32	188	0.00447	0.00451	−0.000599	
LAPM WA	42	CC3	1/07—07:28:07	1/07—11:54:32	399	0.00476	0.00476	0.000114	
	51	CC3	1/07—12:22:32	1/07—13:53:32	76	0.00252	0.00255	0.000392	
	51	CC3	1/07—18:03:32	1/07—19:06:32	35	0.00512	0.00513	−0.0000832	
LAPM YA	42	CC3	1/07—07:28:17	1/07—11:54:32	398	0.00419	0.00419	−0.000148	
	51	CC3	1/07—12:22:32	1/07—13:53:32	80	0.00428	0.00428	−0.000110	
	51	CC3	1/07—18:03:32	1/07—19:05:32	34	0.00567	0.00568	0.000187	
	61	CC3	1/07—14:56:32	1/07—17:53:32	172	0.00210	0.00219	−0.000632	
LAPM YB	42	CC3	1/07—07:28:17	1/07—11:54:32	398	0.00429	0.00430	−0.000294	
	51	CC3	1/07—12:22:32	1/07—13:53:32	79	0.00397	0.00399	0.000389	
	51	CC3	1/07—18:03:32	1/07—19:41:32	53	0.00468	0.00474	0.000755	
	61	CC3	1/07—14:56:32	1/07—17:53:32	172	0.00227	0.00227	0.000123	

Table 41 (contd)

Orbit identification	DSS	Data type	Beginning data time, mo/day—GMT	End data time, mo/day—GMT	No. of points	Standard deviation	rms	Mean error	Remarks
LAPM YC	11	CC3	1/07—21:24:32	1/07—22:16:32	51	0.00312	0.00386	0.00240	
	42	CC3	1/07—07:28:07	1/07—11:54:32	399	0.00920	0.00965	−0.00291	
	51	CC3	1/07—12:22:32	1/07—13:53:32	80	0.00200	0.0123	0.0121	
	51	CC3	1/07—18:03:32	1/07—21:12:32	119	0.00759	0.0122	0.09956	
	61	CC3	1/07—14:03:32	1/07—17:53:32	188	0.00733	0.00921	−0.00558	
PRCL YC	11	CC3	1/07—21:24:32	1/07—23:07:32	98	0.00276	0.00317	0.00156	
	42	CC3	1/07—07:28:07	1/07—11:54:32	399	0.00871	0.00915	−0.00278	
	51	CC3	1/07—12:22:32	1/07—13:53:32	80	0.00210	0.0123	0.0121	
	51	CC3	1/07—18:03:32	1/07—21:12:32	119	0.00774	0.0124	0.00974	
	61	CC3	1/07—14:56:32	1/07—17:53:32	172	0.00781	0.00979	−0.00591	
PRCL YD	11	CC3	1/07—21:24:32	1/07—23:07:32	98	0.00286	0.00330	0.00165	
	42	CC3	1/07—07:28:07	1/07—11:54:32	399	0.00688	0.00721	−0.00216	
	51	CC3	1/07—12:22:32	1/07—13:53:32	80	0.00178	0.00745	0.00723	
	51	CC3	1/07—18:03:32	1/07—21:12:32	119	0.00606	0.00894	0.00658	
	61	CC3	1/07—14:56:32	1/07—17:53:32	172	0.00744	0.00823	−0.00352	
PRCL YE	11	CC3	1/07—21:24:32	1/07—23:07:32	98	0.00280	0.00319	0.00153	
	42	CC3	1/07—07:28:07	1/07—11:54:32	399	0.00679	0.00706	−0.00192	
	51	CC3	1/07—12:22:32	1/07—13:53:32	80	0.00178	0.00710	0.00687	
	51	CC3	1/07—18:03:32	1/07—21:12:32	119	0.00604	0.00873	0.00629	
	61	CC3	1/07—14:56:32	1/07—17:53:32	172	0.00719	0.00790	−0.00327	
1POM WA	11	CC3	1/07—23:45:32	1/08—04:24:32	720	0.00591	0.00598	−0.000886	Eight minutes (01:14–01:22) of DSS 11 data were 10-s sample rate. All other post-midcourse data were 60-s sample rate
1POM WD	11	CC3	1/07—23:45:32	1/08—05:23:32	361	0.00318	0.00318	−0.0000534	
	42	CC3	1/08—05:34:32	1/08—06:09:32	36	0.00322	0.00325	0.000434	
1POM WF	11	CC3	1/07—23:45:32	1/08—05:23:32	361	0.00320	0.00320	0.0000210	
	42	CC3	1/08—05:34:32	1/08—08:24:32	170	0.00289	0.00289	−0.0000359	
2POM WA	11	CC3	1/07—23:45:32	1/08—05:23:32	361	0.00317	0.00317	0.0000568	
	42	CC3	1/08—05:34:32	1/08—09:14:32	218	0.00273	0.00273	0.0000706	
3POM YA	11	CC3	1/07—23:45:32	1/08—05:23:32	355	0.00322	0.00322	0.0000805	
	42	CC3	1/08—05:34:32	1/08—12:44:32	327	0.00245	0.00245	−0.0000149	
3POM YB	11	CC3	1/07—23:45:32	1/08—05:23:32	355	0.00460	0.00463	0.000496	
	42	CC3	1/08—05:34:32	1/08—12:38:32	326	0.00305	0.00318	−0.000915	
	51	CC3	1/08—12:49:32	1/08—14:37:32	64	0.00730	0.00752	0.00183	
3POM WB	11	CC3	1/07—23:45:32	1/08—05:23:32	361	0.00496	0.00499	0.000517	
	42	CC3	1/08—05:34:32	1/08—12:38:32	409	0.00294	0.00310	−0.000992	
	51	CC3	1/08—12:49:32	1/08—16:23:32	185	0.00499	0.00507	0.000858	
3POM WC	11	CC3	1/07—23:45:32	1/08—05:23:32	361	0.00475	0.00479	0.000671	
	42	CC3	1/08—05:34:32	1/08—12:38:32	409	0.00257	0.00280	−0.00113	
	51	CC3	1/08—13:00:32	1/08—16:23:32	174	0.00463	0.00487	0.00151	
	61	CC3	1/08—16:34:32	1/08—17:01:32	28	0.00173	0.00342	−0.00295	
3POM YD	51	CC3	1/08—13:00:32	1/08—15:58:32	149	0.00543	0.00551	0.000943	Eight minutes (01:14–01:22) of DSS 11 data were 10-s sample rate. All other post-midcourse data were 60-s sample rate
	61	CC3	1/08—16:34:32	1/08—18:23:32	104	0.00354	0.00370	−0.00106	
	61	CC3	1/08—20:33:32	1/08—20:37:32	5	0.000826	0.0173	0.0172	
	11	CC3	1/07—23:45:32	1/08—05:23:32	361	0.00460	0.00462	0.000479	
	42	CC3	1/08—05:34:32	1/08—12:38:32	409	0.00284	0.00296	−0.000833	

Table 41 (contd)

Orbit identification	DSS	Data type	Beginning data time, mo/day—GMT	End data time, mo/day—GMT	No. of points	Standard deviation	rms	Mean error	Remarks
4POM WA	11	CC3	1/07—23:45:32	1/08—05:23:32	361	0.00375	0.00376	0.000171	
	42	CC3	1/08—05:34:32	1/08—12:38:32	409	0.00484	0.00492	−0.000883	
	51	CC3	1/08—13:00:32	1/08—16:23:32	174	0.00597	0.00598	0.000276	
	51	CC3	1/08—18:34:32	1/08—20:23:32	60	0.00261	0.0109	0.0106	
	61	CC3	1/08—16:34:32	1/08—18:23:32	104	0.00309	0.00628	−0.00546	
	61	CC3	1/08—20:33:32	1/08—20:55:32	21	0.00162	0.00968	0.00954	
4POM WB	11	CC3	1/07—23:45:32	1/08—05:23:32	361	0.00353	0.00354	−0.000288	
	11	CC3	1/08—22:33:32	1/08—22:45:32	5	0.00159	0.00375	−0.00339	
	42	CC3	1/08—05:34:32	1/08—12:38:32	409	0.00645	0.00646	−0.000363	
	51	CC3	1/08—13:00:32	1/08—16:23:32	174	0.00524	0.00526	0.000502	
	51	CC3	1/08—18:34:32	1/08—20:23:32	74	0.00215	0.00646	0.00609	
	61	CC3	1/08—16:34:32	1/08—18:23:32	104	0.00337	0.00990	−0.00931	
	61	CC3	1/08—20:33:32	1/08—22:23:32	104	0.00231	0.00703	0.00664	
4POM WC	11	CC3	1/07—23:45:32	1/08—05:23:32	361	0.00408	0.00411	0.000552	Eight minutes (01:14–01:22) of DSS 11 data were 10-s sample rate. All other post-midcourse data were 60-s sample rate
	11	CC3	1/08—22:33:32	1/08—23:30:32	49	0.00377	0.00383	−0.000693	
	42	CC3	1/08—05:34:32	1/08—12:38:32	409	0.00360	0.00384	−0.00133	
	51	CC3	1/08—13:00:32	1/08—16:23:32	174	0.00579	0.00623	0.00230	
	51	CC3	1/08—18:34:32	1/08—20:23:32	74	0.00213	0.00463	0.00411	
	61	CC3	1/08—16:34:32	1/08—18:23:32	104	0.00238	0.00497	−0.00436	
	61	CC3	1/08—20:33:32	1/08—22:23:32	104	0.00170	0.00248	0.00180	
4POM WD	11	CC3	1/07—23:45:32	1/08—05:23:32	361	0.00367	0.00367	0.0000991	
	11	CC3	1/08—22:33:32	1/09—00:45:32	125	0.00412	0.00414	−0.000432	
	42	CC3	1/08—05:34:32	1/08—12:38:32	409	0.00367	0.00374	−0.000734	
	51	CC3	1/08—13:00:32	1/08—16:23:32	174	0.00465	0.00473	0.000874	
	51	CC3	1/08—18:34:32	1/08—20:23:32	108	0.00251	0.00362	0.00260	
	61	CC3	1/08—16:34:32	1/08—18:23:32	104	0.00313	0.00421	−0.00281	
	61	CC3	1/08—20:33:32	1/08—22:23:32	104	0.00156	0.00208	0.00137	
4POM WG	11	CC3	1/07—23:47:32	1/08—05:22:02	75	0.00220	0.00257	−0.00132	
	11	CC3	1/08—22:33:32	1/09—04:21:02	69	0.00318	0.00356	−0.00160	
	42	CC3	1/08—05:36:32	1/08—12:36:32	81	0.00736	0.00739	0.000732	
	61	CC3	1/08—13:02:32	1/08—18:22:02	22	0.00279	0.00434	−0.00333	
	61	CC3	1/08—20:35:32	1/08—22:22:02	22	0.00132	0.00983	0.00974	
4POM WH	11	CC3	1/07—23:47:32	1/08—05:22:02	75	0.00195	0.00201	−0.000469	Eight minutes (01:14–01:22) of DSS 11 data were 10-s sample rate. All other post-midcourse data were 60-s sample rate
	11	CC3	1/08—22:33:32	1/09—04:55:02	75	0.00458	0.00478	−0.00137	
	42	CC3	1/08—05:36:32	1/08—12:36:32	81	0.00597	0.00606	−0.00102	
	51	CC3	1/08—13:02:32	1/08—16:23:02	33	0.00332	0.00389	0.00201	
	51	CC3	1/08—18:36:32	1/08—20:21:32	18	0.00131	0.0103	0.0103	
4POM WI	11	CC3	1/07—23:47:32	1/08—05:22:02	75	0.00228	0.00236	−0.000625	
	11	CC3	1/08—22:33:32	1/09—05:32:32	83	0.00617	0.00617	−0.000141	
	42	CC3	1/08—05:36:32	1/08—12:36:32	81	0.00520	0.00521	0.000214	
	51	CC3	1/08—13:02:32	1/08—16:23:02	30	0.00191	0.00228	0.00125	
4POM WP	11	CC3	1/07—23:47:32	1/08—05:22:02	75	0.00234	0.00243	0.00641	
	11	CC3	1/08—22:33:32	1/09—05:58:32	88	0.00919	0.00944	−0.00217	
	42	CC3	1/08—05:36:32	1/08—12:36:32	81	0.00527	0.00530	−0.000546	
	42	CC3	1/09—06:05:32	1/09—09:46:02	44	0.00605	0.00812	0.00542	
	51	CC3	1/08—13:02:32	1/08—16:23:02	33	0.00304	0.00304	−0.0000074	

Table 41 (contd)

Orbit identification	DSS	Data type	Beginning data time, mo/day—GMT	End data time, mo/day—GMT	No. of points	Standard deviation	rms	Mean error	Remarks
4PCM YK	11	CC3	1/07—23:45:32	1/08—05:23:32	359	0.00329	0.00329	0.000182	
	11	CC3	1/08—22:33:32	1/09—05:58:32	415	0.00321	0.00321	0.000107	
	42	CC3	1/08—05:34:32	1/08—12:38:32	396	0.00276	0.00278	−0.000324	
	42	CC3	1/09—06:03:32	1/09—07:25:32	78	0.00376	0.00663	0.00549	
	51	CC3	1/08—13:00:32	1/08—16:23:32	148	0.00288	0.00309	0.00113	
4POM YN	11	CC3	1/07—23:45:32	1/08—05:23:32	359	0.0158	0.0159	0.000790	
	11	CC3	1/08—22:33:32	1/09—05:58:32	415	0.00722	0.00725	−0.000687	
	42	CC3	1/08—05:34:32	1/08—12:38:32	396	0.00744	0.00744	−0.0000931	
	42	CC3	1/09—06:03:32	1/09—13:29:32	415	0.00751	0.00751	−0.0000256	
	51	CC3	1/08—13:00:32	1/08—16:23:32	148	0.00712	0.00764	−0.00279	
	51	CC3	1/08—18:34:32	1/08—20:23:32	108	0.00731	0.00739	0.00105	
	51	CC3	1/09—13:33:32	1/09—14:41:32	44	0.00788	0.0144	0.0120	
	61	CC3	1/08—16:34:32	1/08—18:23:32	102	0.00716	0.00740	−0.00188	
	61	CC3	1/08—20:33:32	1/08—22:23:32	104	0.00598	0.00608	0.00112	
5POM YA	11	CC3	1/07—23:45:32	1/08—05:23:32	359	0.0157	0.0157	−0.000191	
	11	CC3	1/08—22:33:32	1/09—05:58:32	415	0.00688	0.00688	−0.000104	
	42	CC3	1/08—05:34:32	1/08—12:38:32	396	0.00759	0.00759	0.0000814	
	42	CC3	1/09—06:03:32	1/09—13:29:32	415	0.00720	0.00722	−0.000571	
	51	CC3	1/08—13:00:32	1/08—16:23:32	148	0.00720	0.00751	−0.00212	
	51	CC3	1/08—18:34:32	1/08—20:23:32	108	0.00734	0.00747	0.00140	
	51	CC3	1/08—13:33:32	1/09—15:27:32	81	0.00702	0.00804	0.00392	
	61	CC3	1/08—16:34:32	1/08—18:23:32	102	0.00699	0.00700	0.000333	
	61	CC3	1/08—20:33:32	1/08—22:23:32	104	0.00600	0.00623	0.00168	
	61	CC3	1/09—15:38:32	1/09—17:03:32	64	0.00708	0.00727	−0.00163	
5POM YD	11	CC3	1/07—23:45:32	1/08—05:23:32	359	0.00361	0.00361	−0.0000666	Eight minutes (01:14–01:22) of DSS 11 data were 10-s sample rate. All other post-midcourse data were 60-s sample rate
	11	CC3	1/08—22:33:32	1/08—05:58:32	415	0.00330	0.00333	−0.000494	
	42	CC3	1/08—05:34:32	1/08—12:38:32	396	0.00384	0.00385	0.000249	
	42	CC3	1/09—06:03:32	1/09—13:29:32	415	0.00260	0.00274	−0.000864	
	51	CC3	1/08—13:00:32	1/08—16:23:32	148	0.00343	0.00400	−0.00207	
	51	CC3	1/08—18:34:32	1/08—20:23:32	108	0.00226	0.00235	0.000628	
	51	CC3	1/09—13:33:32	1/09—15:27:32	81	0.00479	0.00726	0.00546	
	51	CC3	1/09—18:03:32	1/09—20:31:32	116	0.00300	0.00333	0.00145	
	61	CC3	1/08—16:34:32	1/08—18:23:32	102	0.00227	0.00235	−0.000582	
	61	CC3	1/08—20:33:32	1/08—22:23:32	104	0.00142	0.00429	0.00405	
	61	CC3	1/09—15:33:32	1/09—17:53:32	127	0.00310	0.00343	−0.00148	
5POM WE	11	CC3	1/07—23:55:32	1/08—05:23:32	351	0.00318	0.00373	0.00195	
	11	CC3	1/08—22:33:32	1/09—05:58:32	408	0.00617	0.00834	−0.00562	
	42	CC3	1/08—05:34:32	1/08—12:38:32	396	0.00775	0.00827	−0.00288	
	42	CC3	1/09—06:03:32	1/09—12:59:32	391	0.00460	0.00708	0.00538	
	51	CC3	1/08—13:00:32	1/08—16:23:32	148	0.00332	0.00338	−0.000632	
	51	CC3	1/08—18:34:32	1/08—20:23:32	81	0.00218	0.00479	0.00427	
	51	CC3	1/09—18:03:32	1/09—20:52:32	131	0.0115	0.0116	0.0116	
	61	CC3	1/08—16:34:32	1/08—18:23:32	102	0.00306	0.00754	−0.00689	
	61	CC3	1/08—20:33:32	1/08—22:23:32	104	0.00208	0.00762	0.00733	
	61	CC3	1/09—16:00:32	1/09—17:53:32	109	0.00247	0.00254	0.000609	

Table 41 (contd)

Orbit identification	DSS	Data type	Beginning data time, mo/day—GMT	End data time, mo/day—GMT	No. of points	Standard deviation	rms	Mean error	Remarks
FINAL WA	11	CC3	1/09—22:03:32	1/09—22:54:32	52	0.00251	0.00251	0.000120	Eight minutes (01:14–01:22) of DSS 11 data were 10-s sample rate. All other post-midcourse data were 60-s sample rate
	51	CC3	1/09—19:21:32	1/09—21:53:32	139	0.00279	0.00279	0.00000351	
FINAL YA	11	CC3	1/09—22:03:32	1/09—22:59:32	55	0.00314	0.00314	0.0000599	
	51	CC3	1/09—19:21:32	1/09—21:53:32	137	0.00278	0.00278	0.00000535	
FINAL YB	11	CC3	1/09—22:03:32	1/09—23:16:32	65	0.00331	0.00331	0.0000639	
	51	CC3	1/09—19:21:32	1/09—21:53:32	137	0.00285	0.00285	−0.00000178	
FINAL WC	11	CC3	1/09—22:03:32	1/09—23:29:32	76	0.00258	0.00258	0.0000112	
	51	CC3	1/09—19:21:32	1/09—21:53:32	139	0.00289	0.00289	0.0000457	
FINAL YC	11	CC3	1/09—22:03:32	1/09—23:55:32	94	0.00233	0.00233	0.0000260	
	51	CC3	1/09—19:21:32	1/09—21:53:32	137	0.00286	0.00286	0.0000873	
FINAL WD	11	CC3	1/09—22:03:32	1/09—23:59:32	97	0.00282	0.00285	0.000409	
	51	CC3	1/09—19:21:32	1/09—21:53:32	139	0.00282	0.00282	0.0000263	
FINAL WE	11	CC3	1/09—22:03:32	1/09—00:15:32	109	0.00275	0.00279	0.000484	
	51	CC3	1/09—19:21:32	1/09—21:53:32	139	0.00281	0.00281	0.0000913	
FINAL YD	11	CC3	1/09—22:03:32	1/10—00:14:32	110	0.00219	0.00219	−0.0000366	
	51	CC3	1/09—19:21:32	1/09—21:53:32	137	0.00282	0.00282	0.0000891	
FINAL WF	11	CC3	1/09—22:03:32	1/10—00:20:32	117	0.00227	0.00227	−0.0000449	
	51	CC3	1/09—19:21:32	1/09—21:53:32	139	0.00280	0.00280	0.0000457	
FINAL YE	11	CC3	1/09—22:03:32	1/10—00:20:32	116	0.00229	0.00229	−0.0000274	
	51	CC3	1/09—19:21:32	1/09—21:53:32	132	0.00282	0.00282	0.0000481	
PTD-1	11	CC3	1/07—23:45:32	1/08—05:23:32	359	0.00355	0.00369	−0.00101	Eight minutes (01:14–01:22) of DSS 11 data was 10-s sample rate. All other post-midcourse data were 60-s midcourse data were 60-s sample rate
	11	CC3	1/08—22:33:32	1/09—05:58:32	415	0.00297	0.00298	0.000182	
	11	CC3	1/09—22:03:32	1/10—00:20:32	116	0.00801	0.00816	−0.00157	
	42	CC3	1/08—05:34:32	1/08—12:38:32	396	0.00355	0.00420	0.00225	
	42	CC3	1/08—05:34:32	1/08—12:38:32	396	0.00355	0.00420	0.00225	
	42	CC3	1/09—06:03:32	1/09—13:29:32	415	0.00267	0.00367	−0.00251	
	51	CC3	1/08—13:00:32	1/08—16:23:32	148	0.00541	0.00550	−0.000968	
	51	CC3	1/08—18:34:32	1/08—20:23:32	108	0.00231	0.00597	−0.00550	
	51	CC3	1/09—13:33:32	1/09—15:27:32	81	0.00427	0.00561	0.00365	
	51	CC3	1/09—18:03:32	1/09—21:53:32	185	0.00293	0.00719	0.00657	
	61	CC3	1/08—16:34:32	1/08—18:23:32	102	0.00194	0.00209	0.000761	
	61	CC3	1/08—20:35:32	1/08—22:23:32	104	0.00139	0.00350	0.00321	
	61	CC3	1/09—15:33:32	1/09—17:53:32	127	0.00206	0.00395	−0.00336	

The one exception is the launch phase, when little doppler data are available and a quick determination of the orbit necessitates the use of both doppler and angle data. During the *Surveyor VII* Mission, angle data from DSS 42 were used in the orbit determination program during the first pass of this station. In an effort to improve the quality of the angular data to be used in the program, they are first corrected for antenna optical pointing error. The optical pointing error is determined by having the DSN stations optically track several stars at the expected, mission-dependent spacecraft declinations. A polynomial curve fit is then made to the differences between the refraction corrected ephemeris values of the star positions and the observed values as read from the antenna angle encoders. The correction coefficients used in the *Surveyor VII* inflight orbit computations can be seen in Tables 42 and 43.

Experience gained in past missions has shown that the optical pointing error correction coefficients do not remove all systematic pointing errors. This is reasonable since the RF and optical axes of the antenna are not necessarily the same. That is, the RF axis is a function of the position of the quadripod feed, whereas the optical axis is not. Thus, if there is a quadripod deflection (due to thermal effect and/or gravitational loading) at some given instant of time, the optical error and the RF error would not be the same. Furthermore, the optical refraction and the RF refraction are not the same due to the difference in respective wave lengths. In addition to these effects, the RF pointing error is also a function of feed alignment, received signal-to-noise ratio, and received polarization angle (since the antenna null pattern does not have the same slope at all polarization angles).

Since DSS 42 was the initial acquisition station, the angular data taken by this station were the most important such data for use in the early orbits. These data, when fit through the final postflight orbit, show a bias of −0.030 deg in hour angle and 0.035 deg declination. In previous *Surveyor* missions, the correction coefficients for DSS 42 have usually been more effective in hour angle than in declination. For instance, the hour angle and declination angle biases for DSS 42 averaged over the *Surveyors III, V,* and *VI* Missions are −0.010 and −0.040 deg, respectively. This small discrepancy (between previous *Surveyor* missions and *Surveyor VII*) is explained by the fact that the corrections are dependent on declination, and for the particular *Surveyor VII* first pass declination (approximately 10 deg), the corrections produce about the same accuracy in declination as in hour angle. DSS 42 angular residuals for the first pass are seen in Fig. 57. DSS 51 first-pass angular data indicated a bias of +0.035 deg in hour angle and −0.025 deg in declination when fit through the final postflight orbit. These values are quite consistent with previous *Surveyor*/DSS 51 experience; for instance, the hour angle and declination biases averaged over the *Surveyors III, IV, V,* and *VI* Missions are +0.035 and −0.020 deg, respectively. The DSS 51 first-pass angle residuals can be seen in Figs. 58 and 59. DSS 61 angular data (uncorrected) showed biases of −0.020 deg

Table 42. Antenna correction coefficients for DSS 42[a]

Coefficient	Correction	Coefficient	Correction
A_{00}	−2.823094562E −02	B_{00}	1.529098827E −02
A_{01}	5.353777033E −05	B_{01}	3.410829831E −04
A_{02}	−3.082597437E −05	B_{02}	−4.336071801E −06
A_{03}	−6.626461141E −07	B_{03}	6.109815447E −07
A_{10}	−3.171398689E −04	B_{10}	−1.559484352E −04
A_{11}	9.542137245E −06	B_{11}	−2.032267916E −06
A_{12}	−3.367726933E −07	B_{12}	5.779247847E −08
A_{13}	−8.201321554E −09	B_{13}	−2.831355530E −10
A_{20}	1.589100967E −06	B_{20}	−1.186130483E −05
A_{21}	1.835756063E −07	B_{21}	−5.239010283E −08
A_{22}	3.851291638E −09	B_{22}	−2.152496155E −10
A_{23}	−8.191144217E −11	B_{23}	−4.436567279E −11
A_{30}	4.599327736E −08	B_{30}	−2.298149026E −08
A_{31}	3.344301616E −09	B_{31}	8.193320409E −10
A_{32}	1.386713245E −10	B_{32}	−1.910069905E −11
A_{33}	1.816077278E −12	B_{33}	−7.276751867E −13

[a]These corrections are useful for elevations greater than 15 deg, and declinations between N 30 and S 35 deg.

Table 43. Antenna correction coefficients for DSS 51[a]

Coefficient	Correction	Coefficient	Correction
A_{00}	1.241637739E −02	B_{00}	7.580054461E −02
A_{01}	2.788428530E −04	B_{01}	7.158720897E −04
A_{02}	1.107933456E −06	B_{02}	1.265069671E −05
A_{03}	−6.075030236E −09	B_{03}	−4.082247376E −07
A_{10}	−3.906063323E −04	B_{10}	−3.114752889E −05
A_{11}	5.944488677E −06	B_{11}	−4.326730631E −06
A_{12}	−9.943308762E −08	B_{12}	−8.348400771E −07
A_{13}	7.454471863E −10	B_{13}	1.769479559E −08
A_{20}	2.211845590E −06	B_{20}	−7.768849965E −06
A_{21}	1.058964062E −07	B_{21}	−1.697554984E −07
A_{22}	−7.393294554E −10	B_{22}	−3.111461041E −09
A_{23}	−1.914168005E −10	B_{23}	3.246078218E −10
A_{30}	2.123897135E −08	B_{30}	−3.018066365E −08
A_{31}	2.436833188E −09	B_{31}	4.904492523E −10
A_{32}	7.920282695E −11	B_{32}	2.056612252E −10
A_{33}	1.055377395E −12	B_{33}	−3.812621648E −12

[a]These corrections are useful for elevations greater than 15 deg and declinations between N 30 and S 35 deg.

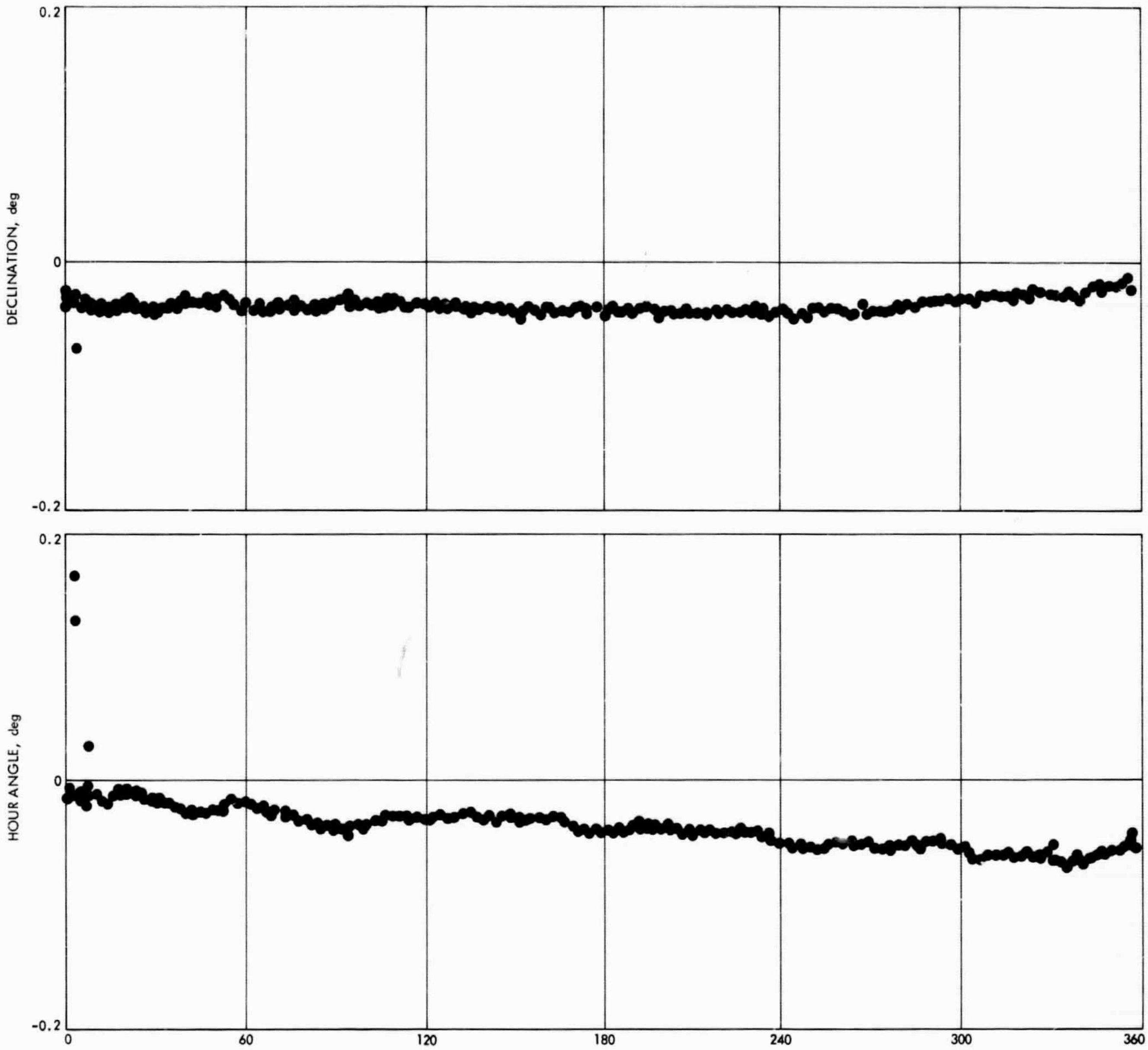


Fig. 57. First pass angular data received by DSS 42 (time from 07:28:00 GMT on January 7, 1968)

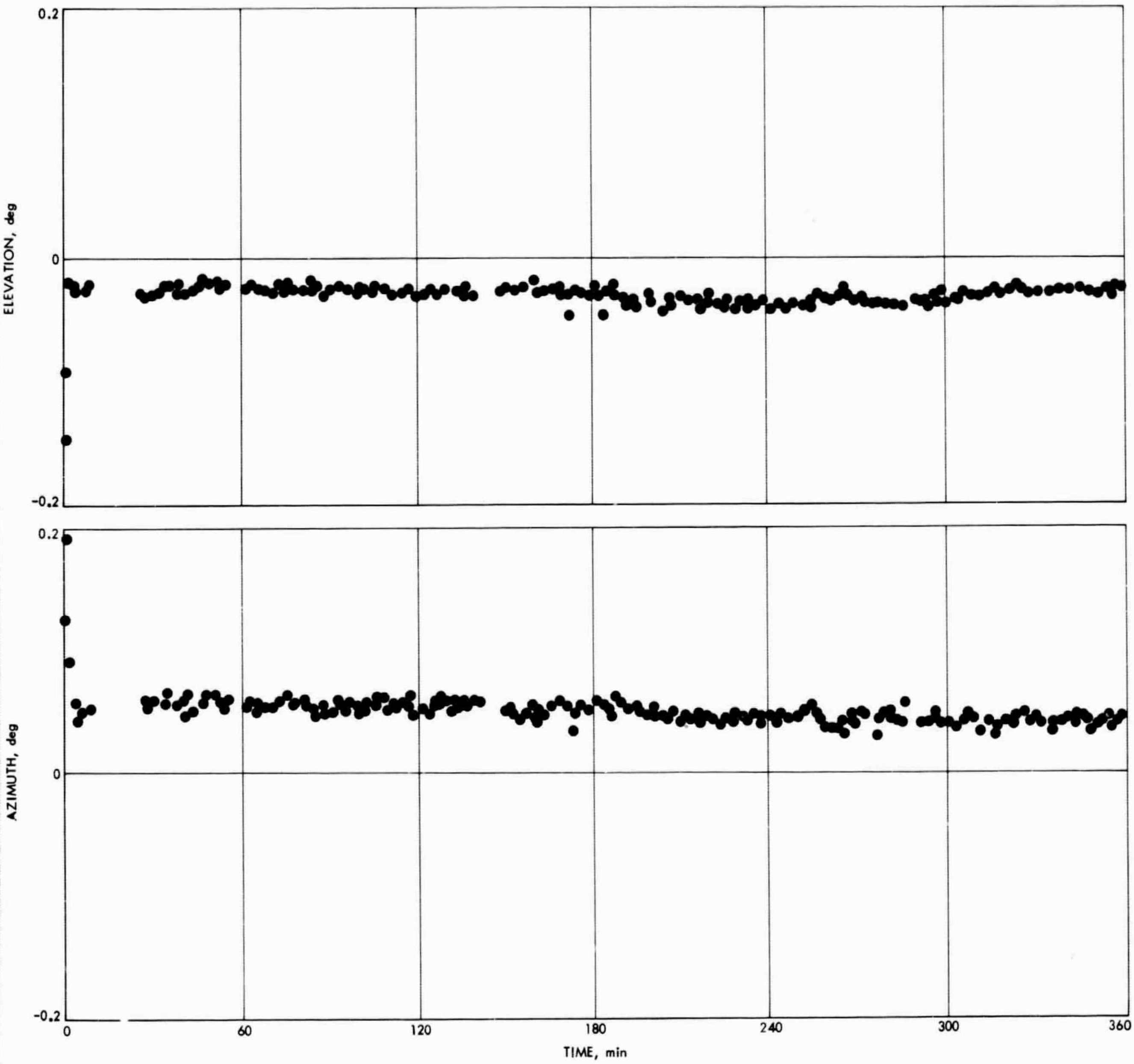


Fig. 58. First pass angular data received by DSS 51 (time from 11:34:00 GMT on January 7, 1968)

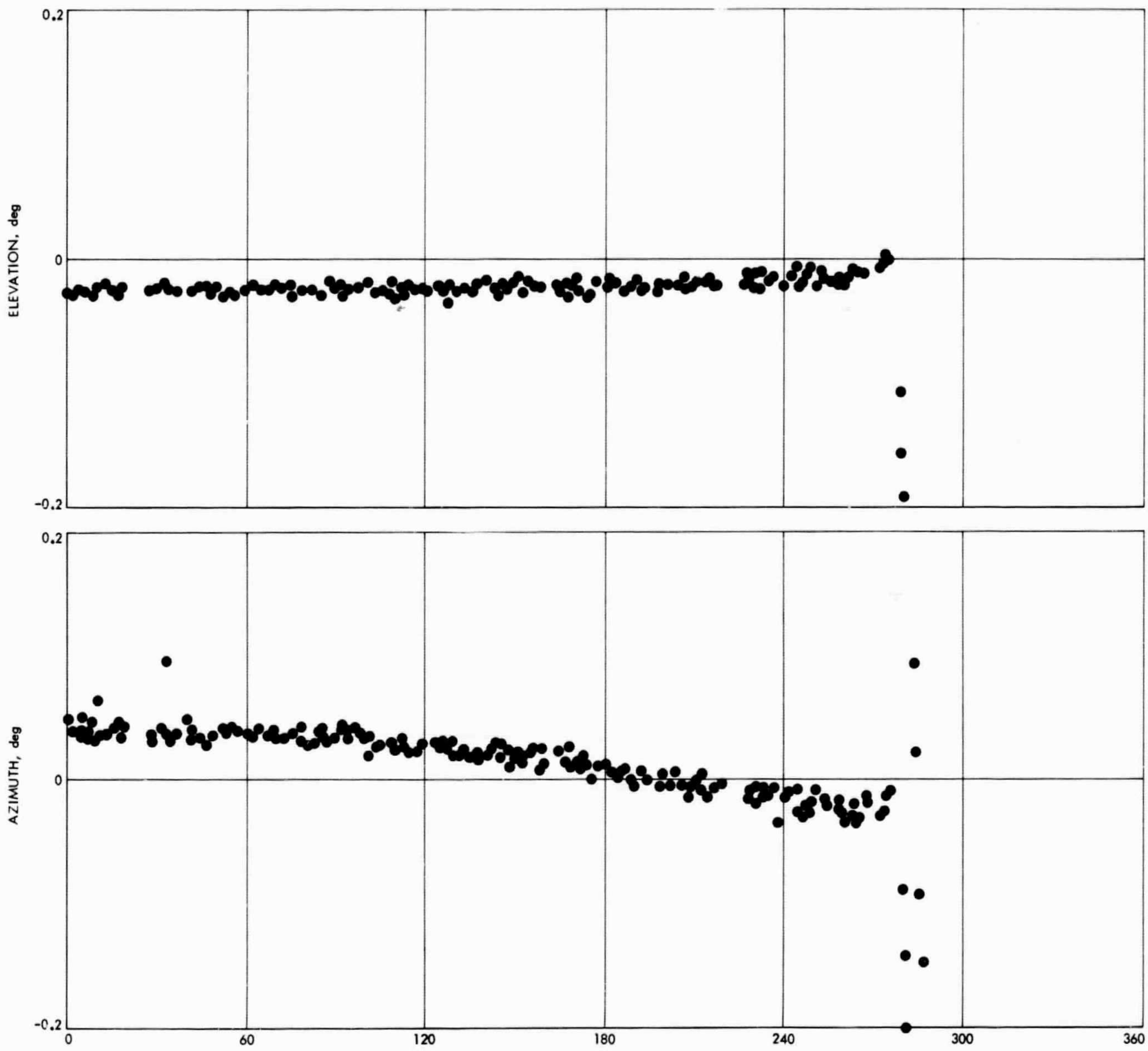


Fig. 59. First pass angular data received by DSS 51 (time from 17:35:00 GMT on January 7, 1968)

in hour angle and −0.015 deg in declination. The DSS 61 first-pass angle residuals can be seen in Figs. 60 and 61.

Doppler tracking. Surveyor VI marked the first use of doppler resolver data during the inflight portion of a *Surveyor* mission, and, considerable operational confidence was gained in its use; for *Surveyor VII*, all participating stations were equipped with doppler resolvers and the data were, of course, used inflight. The tracking and data handling system counts the number of signal zero crossings during a given time interval; this differs from the actual doppler frequency by fractions of a cycle which are alternately lost from one time interval and erroneously added to the next. This error, commonly referred to as truncation error, depends on the data sample rate (clearly, the longer the sample interval, the smaller the relative error); for 60-s count data, this truncation error produces a standard deviation of approximately 0.008 Hz in two-way doppler data. The doppler resolver effectively measures the fraction of a cycle from the start of a time interval to the first zero crossing, and correctly adds it to or subtracts it from the basic frequency measurement. The net result of the use of the doppler resolver for good two-way data is a reduction of the standard deviation by approximately a factor of 4, or, to about 0.002 Hz for 60-s count data.

The first station to view the spacecraft after injection, DSS 42, began taking good two-way, 10-s count doppler data at 07:28:02 GMT on January 7, 1968. The sample rate was changed to 60 s at 08:00:02 GMT and the spacecraft was transferred to DSS 51 at 12:00:02 GMT. The early data from DSS 42 were quite acceptable, showing a standard deviation of 0.005 Hz—a quite nominal figure for a combination of 60- and 10-s count data. DSS 42 two-way doppler residuals are shown in Fig. 62. The DSS 51, which was in the two-way mode from 12:00:02 to 14:00:02, and then again from 18:00:02 to 21:20:02 GMT, took somewhat noisy data, showing a standard deviation of approximately 0.007 Hz for the combined period. This higher-than-expected standard deviation can probably be attributed to a slight degradation of the data during the first portion of the DSS 51 two-way track, when trouble was encountered with a frequency shifter unit. Two-way doppler residuals from DSS 51 are shown in Figs. 63 and 64. First-pass two-way doppler data from DSS 61 was quite nominal, showing a standard deviation of 0.005 Hz. Two-way doppler residuals from DSS 61 first pass are shown in Fig. 65. DSS 11 took quite noisy data during the first (premidcourse) pass, with the two-way doppler residuals indicating a standard deviation of 0.025 Hz for a combination of 60- and 10-s count data. This high noise was caused by the previously mentioned doppler resolver problem encountered by DSS 11 during the first pass. Residuals for this period at DSS 11 are shown in Fig. 66.

b. Midcourse maneuver. Early analysis of the *Surveyor VII* trajectory indicated a midcourse maneuver during the first pass over DSS 11 would be most advantageous, and, therefore, the midcourse maneuver was executed during this pass. Engine ignition was programmed for January 7 at 23:30:09 GMT with a total burn time of 11.35 s. Results of the maneuver as seen in the two-way doppler data over DSS 11 are presented in Fig. 67. As can be seen in the data, the midcourse maneuver resulted in a doppler shift over DSS 11 of approximately +40 Hz.

c. Postmidcourse phase. All midcourse orbit computations used only two-way doppler from the prime stations, DSSs 51, 42, 61, and 11. Very good to excellent two-way doppler data were returned during this period. The DSS 11 two-way doppler residuals during the first pass (postmidcourse) show a standard deviation of 0.0035 Hz —a quite nominal figure for a combination of 60- and 10-s count data. Second-pass two-way doppler residuals show a somewhat high standard deviation of 0.0065 Hz; this was caused by three bad doppler resolver points (see Figs. 78 and 79) which should have been rejected (in the orbit determination program). Third-pass two-way doppler residuals from DSS 11 show a characteristic drift which can probably be attributed to near moon trajectory model errors. The DSS 11 residuals for the postmidcourse phase are shown in Figs. 68–71. The DSS 42 took uniformly good two-way doppler data during the second and third passes—these data showing a standard deviation of 0.004 Hz. The two bad (appearing) points at the end of each pass are due to ground transmitter frequency changes in preparation for spacecraft transfer which were not recorded in the orbit determination program. The DSS 42 two-way doppler residuals for this phase appear in Figs. 72–75. The DSS 51 second- and third-pass data are somewhat degraded by drifts in the early parts of the passes which are probably due to an inadequate refraction model in the orbit determination program (Figs. 76–79). Third-pass data from DSS 51 shows a nominal standard deviation of 0.0045 Hz. Two-way doppler residuals from DSS 51 are shown in Figs. 76–79. Finally, DSS 61 took uniformly excellent two-way doppler data during the second and third passes, these data producing a standard deviation of 0.002 Hz. Two-way doppler residuals for DSS 61 are shown in Figs. 80 and 81.

d. Touchdown phase. Final inflight calculations by the orbit determination group indicated a retroignition time of 01:02:16 GMT on January 10, 1968. A soft landing occurred at 01:05:28 GMT after a flight of 66 h, 35 min, and 27 s. The results of the retroengine burn as seen in the one-way doppler data at DSS 11 are presented in Fig. 82 and the touchdown phase doppler data are shown in Fig. 83. To approximate the varying transmitter frequency during retroburn and touchdown phase, when changing thrust vector precludes the possibility of accurate trajectory predictions, transmitter frequencies reduced from tracking data and predicts up to the burn were extrapolated through touchdown and used to compute range rate. The values of these frequencies and corresponding range rates are presented in Table 44. To approximate the doppler of a stationary spacecraft on the lunar surface, a least-squares quadratic curve fit was made on the data immediately after touchdown. Hopefully, this would remove the major effects of both one-way frequency drift and lunar surface/DSS 11 relative velocity. Table 45 shows the actual doppler received from DSS 11, the hypothetical doppler had the spacecraft been stationary on the lunar surface, the difference between these two doppler values, and the corresponding range rate in feet per second. Figure 84 shows a plot of these values which is the line-of-sight velocity from DSS 11 of the *Surveyor VII* touchdown, referenced to the lunar surface.

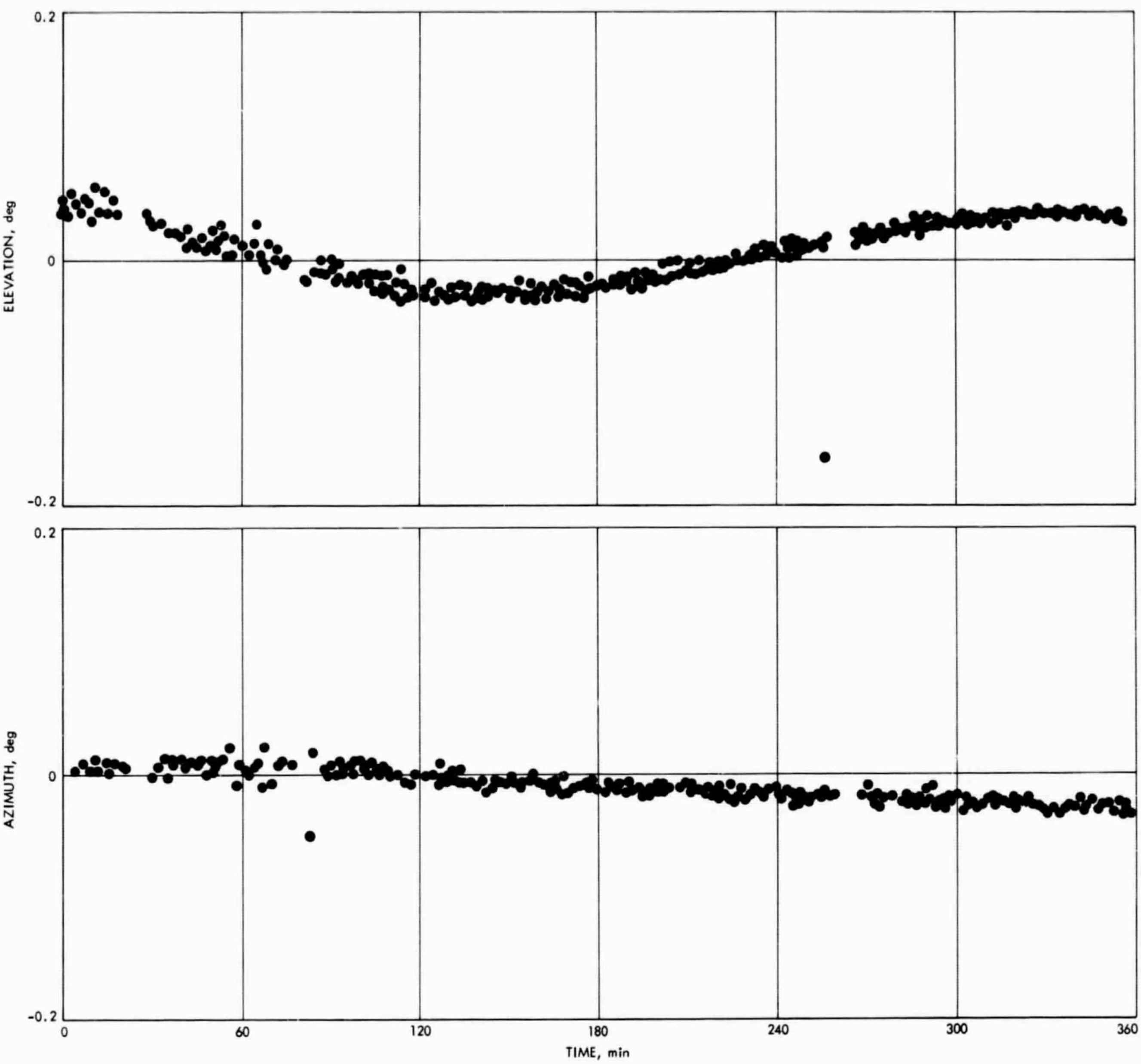


Fig. 60. First pass angular data received by DSS 61 (time from 13:34:00 GMT on January 7, 1968)

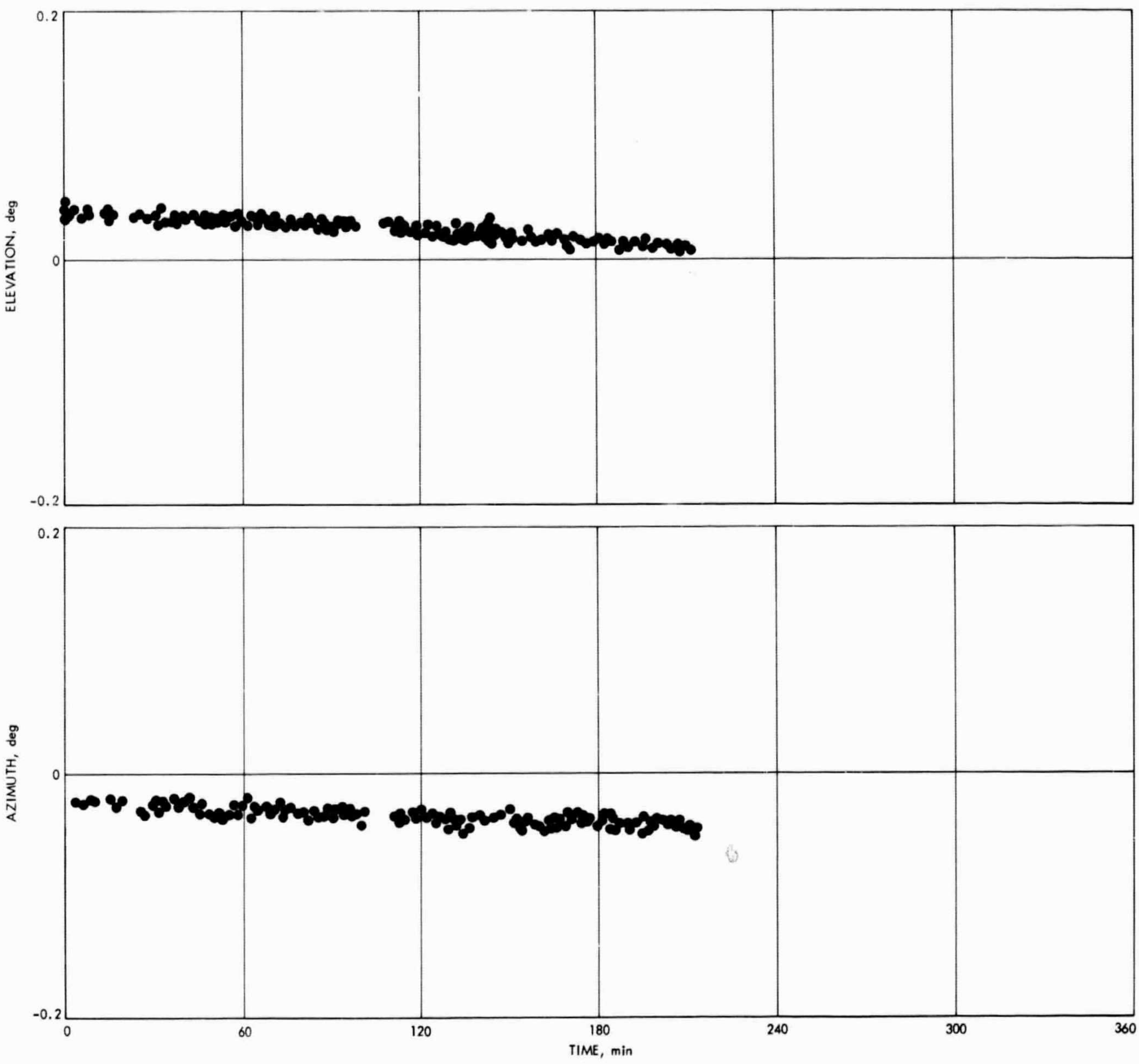


Fig. 61. First pass angular data received by DSS 61 (time from 19:34:00 GMT on January 7, 1968)

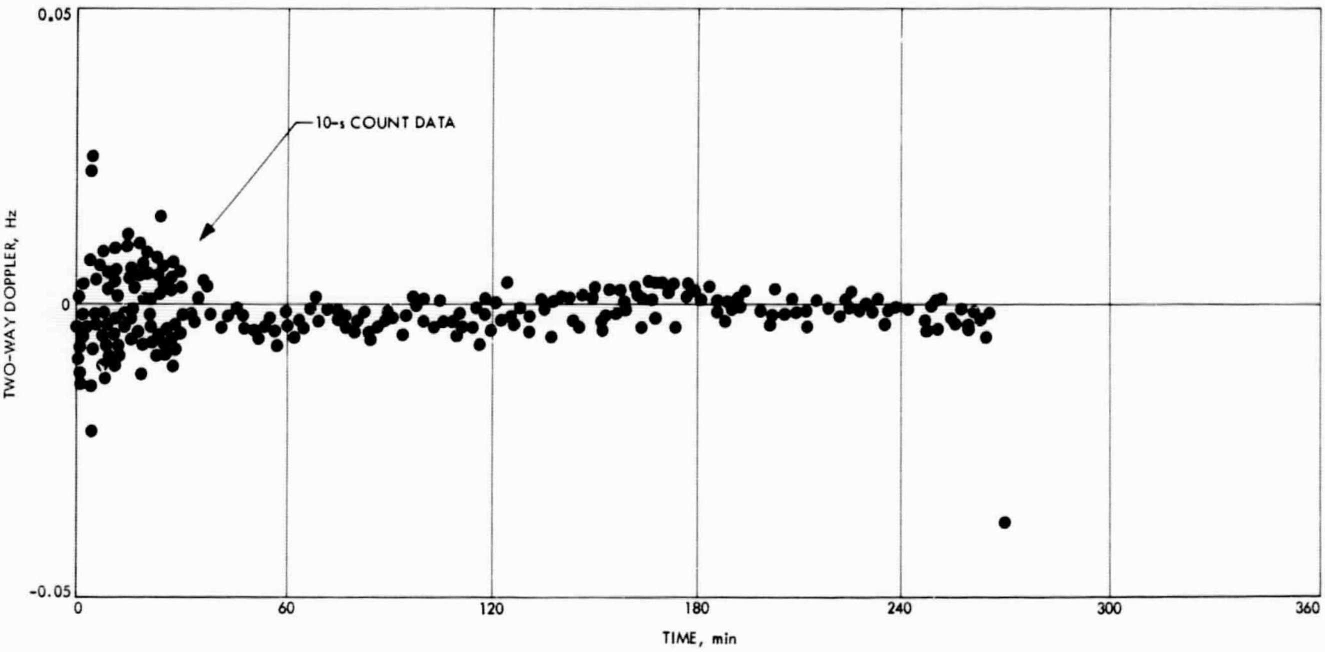


Fig. 62. First pass two-way (CC3) doppler residuals received by DSS 42 (time from 07:28:00 GMT on January 7, 1968)

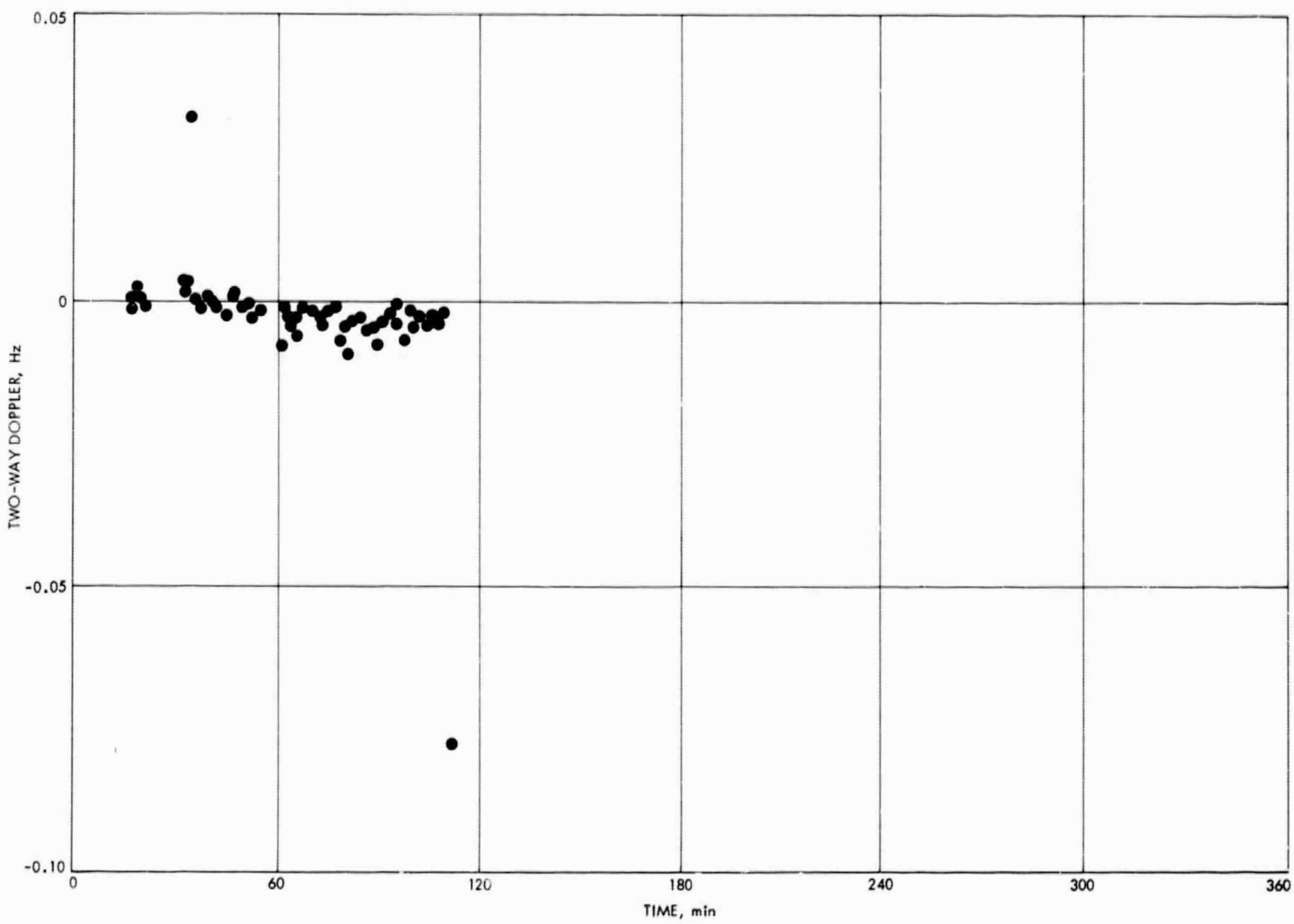


Fig. 63. First pass two-way (CC3) doppler residuals received by DSS 51 (time from 12:02:00 GMT on January 7, 1968)

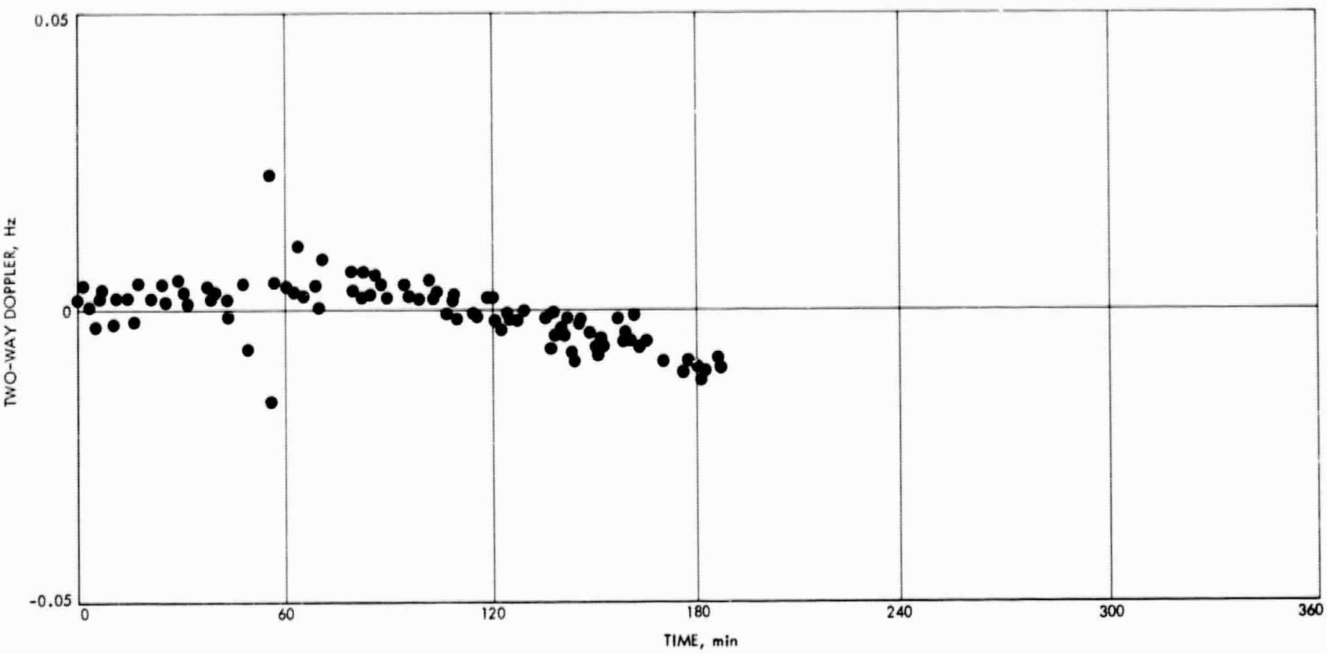


Fig. 64. First pass two-way (CC3) doppler residuals received by DSS 51 (time from 18:03:00 GMT on January 7, 1968)

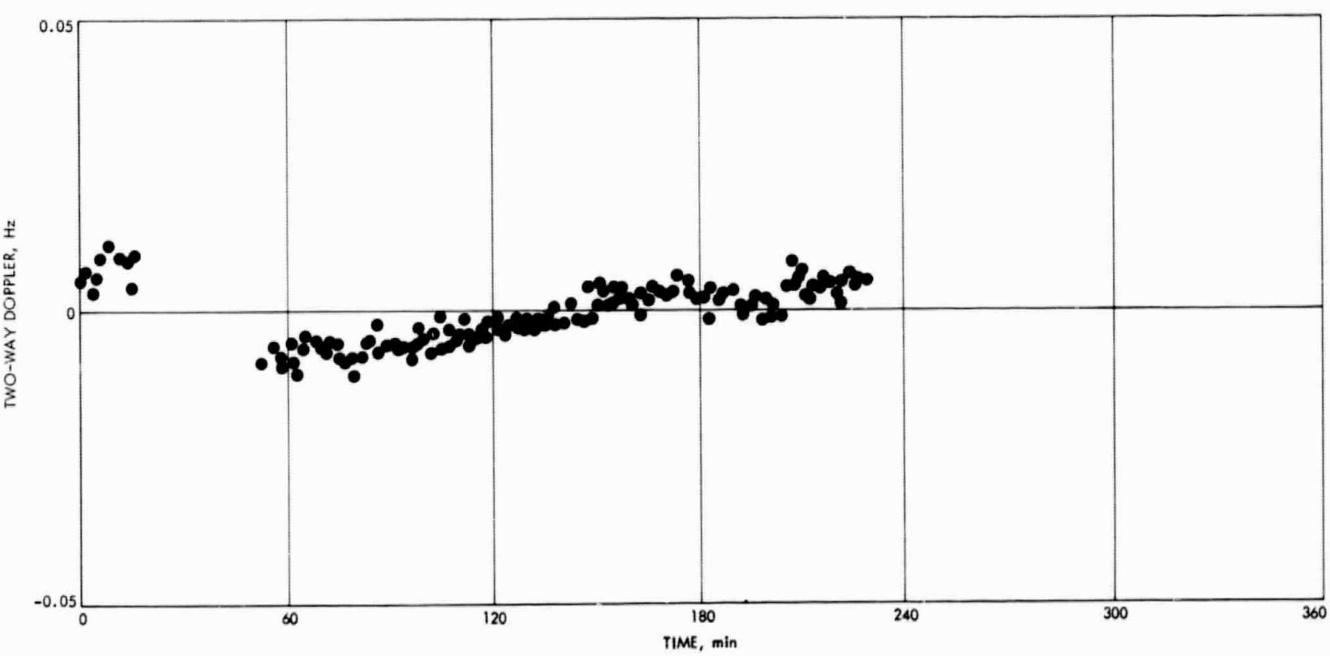


Fig. 65. First pass two-way (CC3) doppler residuals received by DSS 61 (time from 14:03:00 GMT on January 7, 1968)

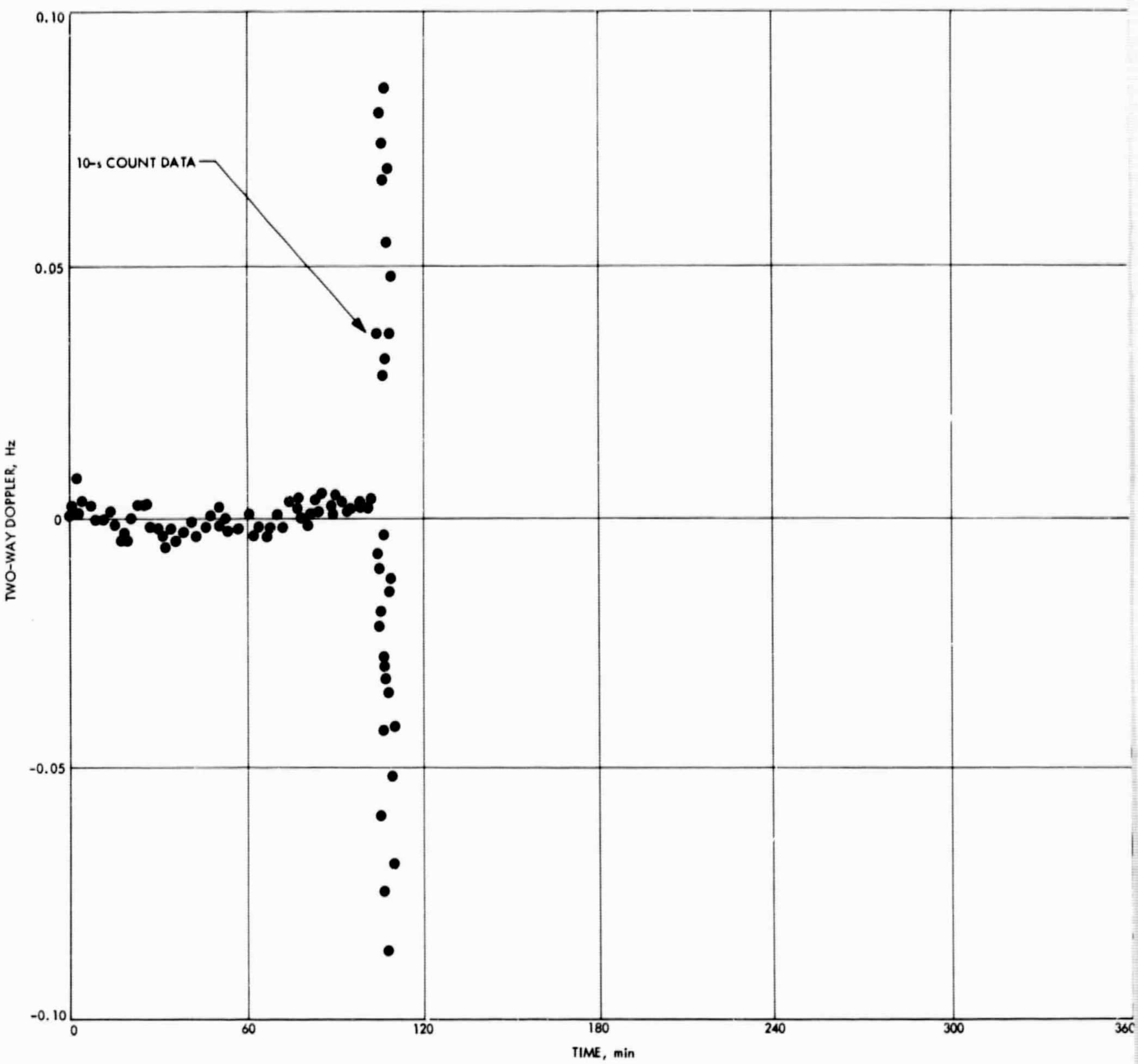


Fig. 66. First pass two-way (CC3) doppler residuals received by DSS 11 (time from 21:24:00 GMT on January 7, 1968)

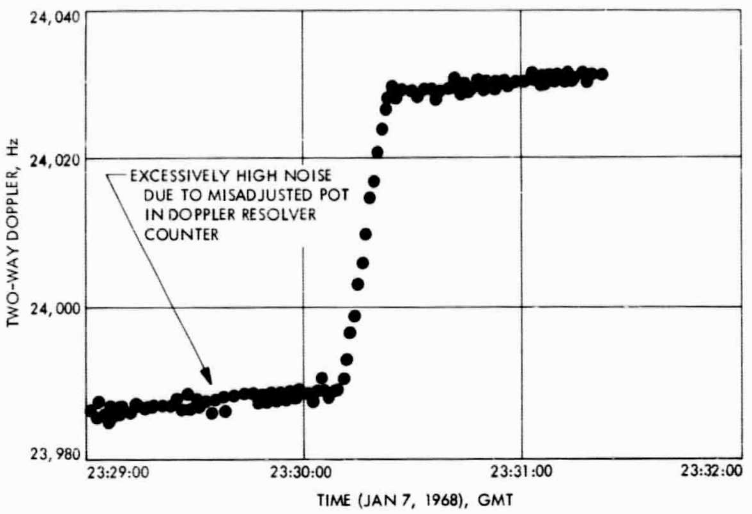


Fig. 67. Midcourse maneuver two-way doppler residuals received by DSS 11 (time from 23:29:00 GMT on January 7, 1968)

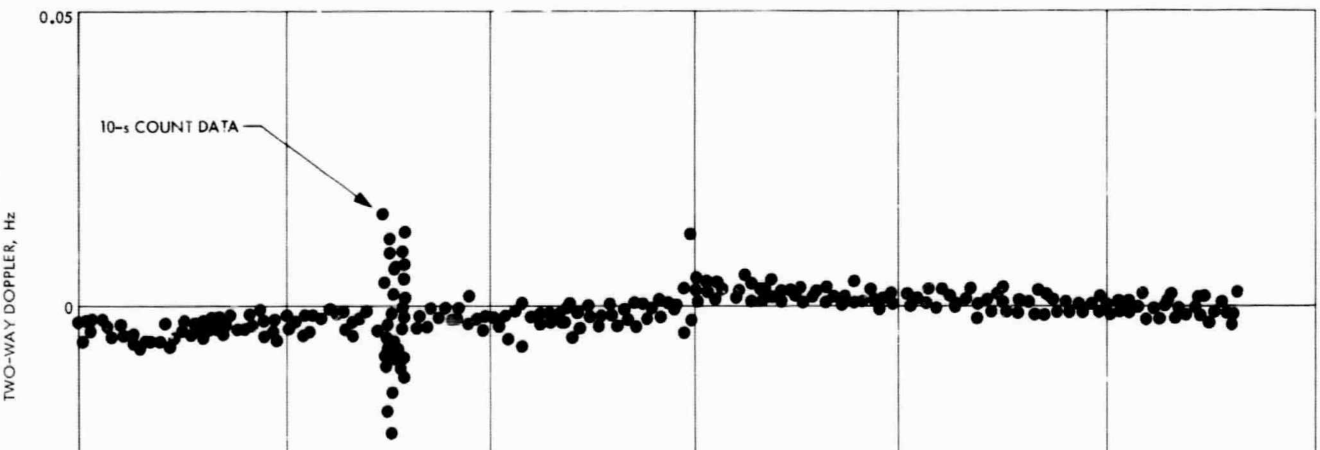


Fig. 68. First pass two-way (CC3) doppler residuals received by DSS 11 (time from 23:45:00 GMT on January 7, 1968)

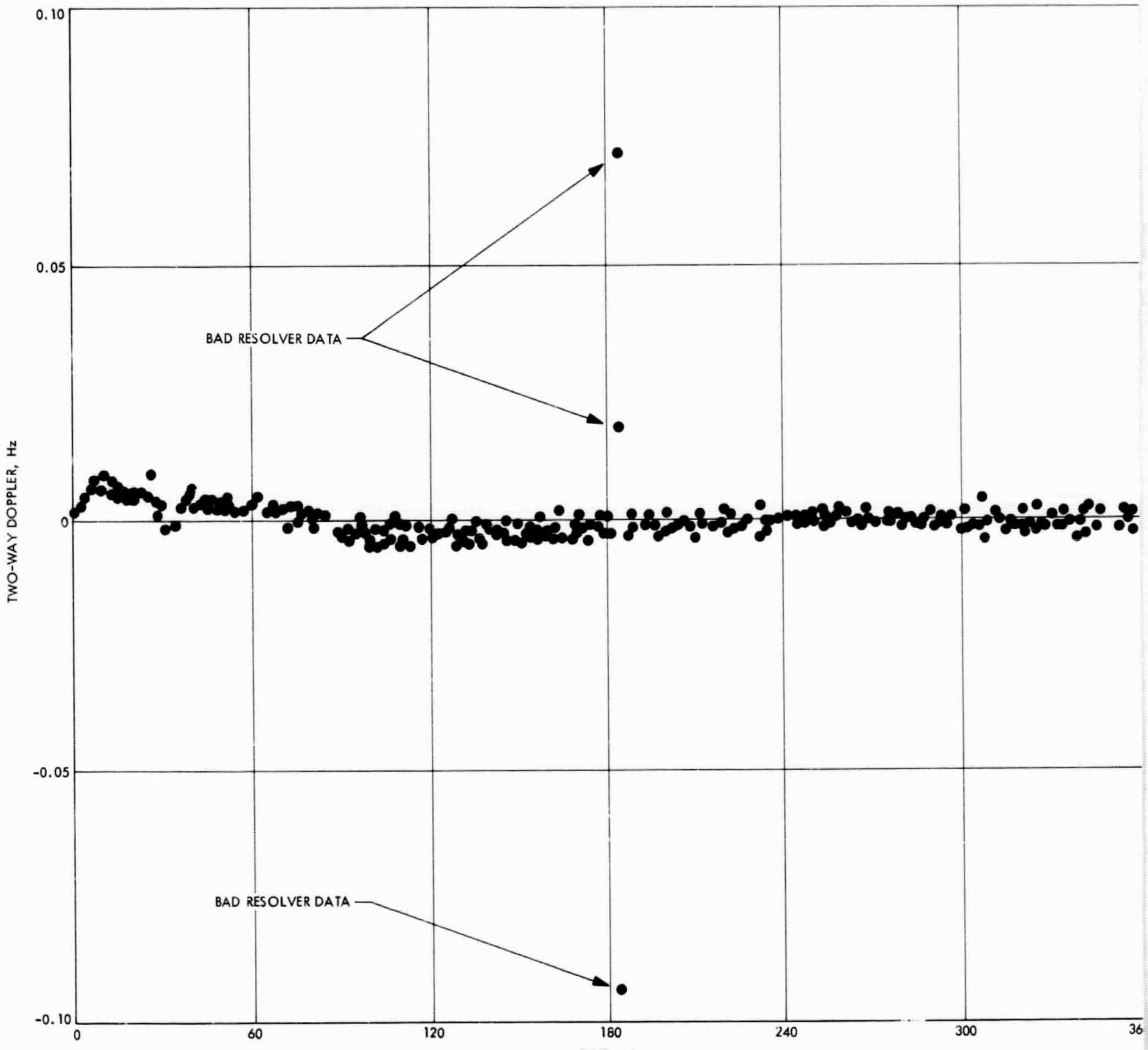


Fig. 69. Second pass two-way (CC3) doppler residuals received by DSS 11 (time from 22:33:00 GMT on January 8, 1968)

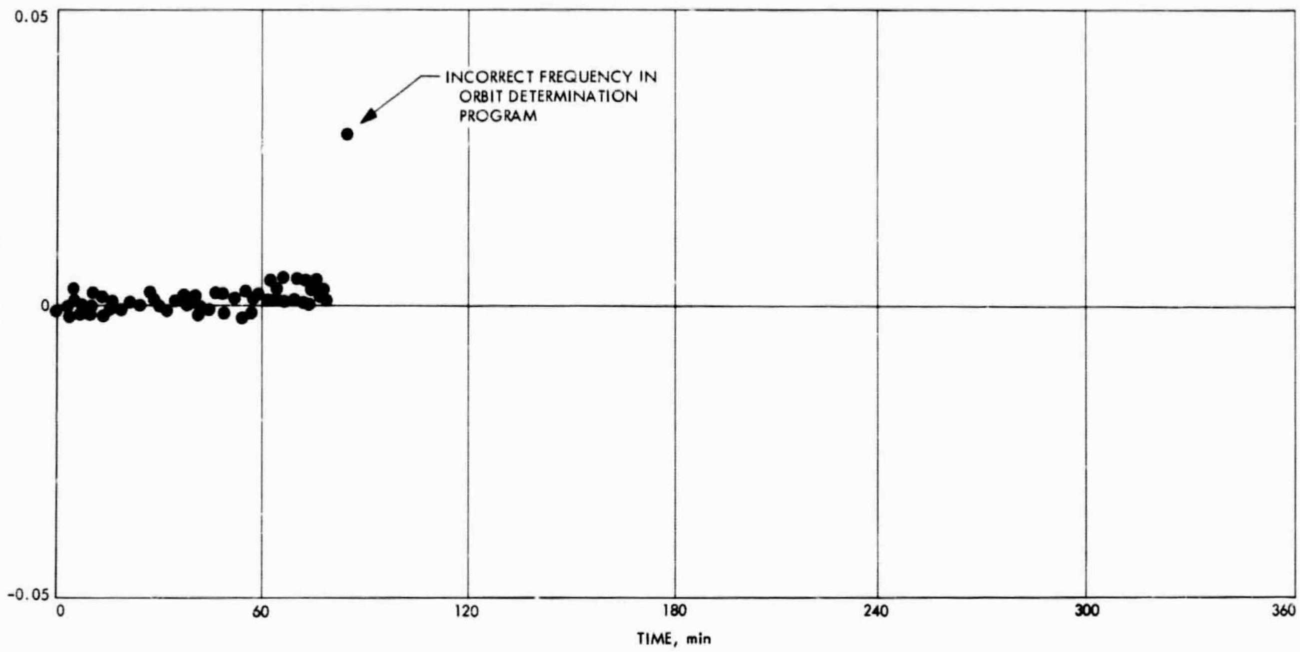


Fig. 70. Second pass two-way (CC3) doppler residuals received by DSS 11 (time from 04:33:00 GMT on January 9, 1968)

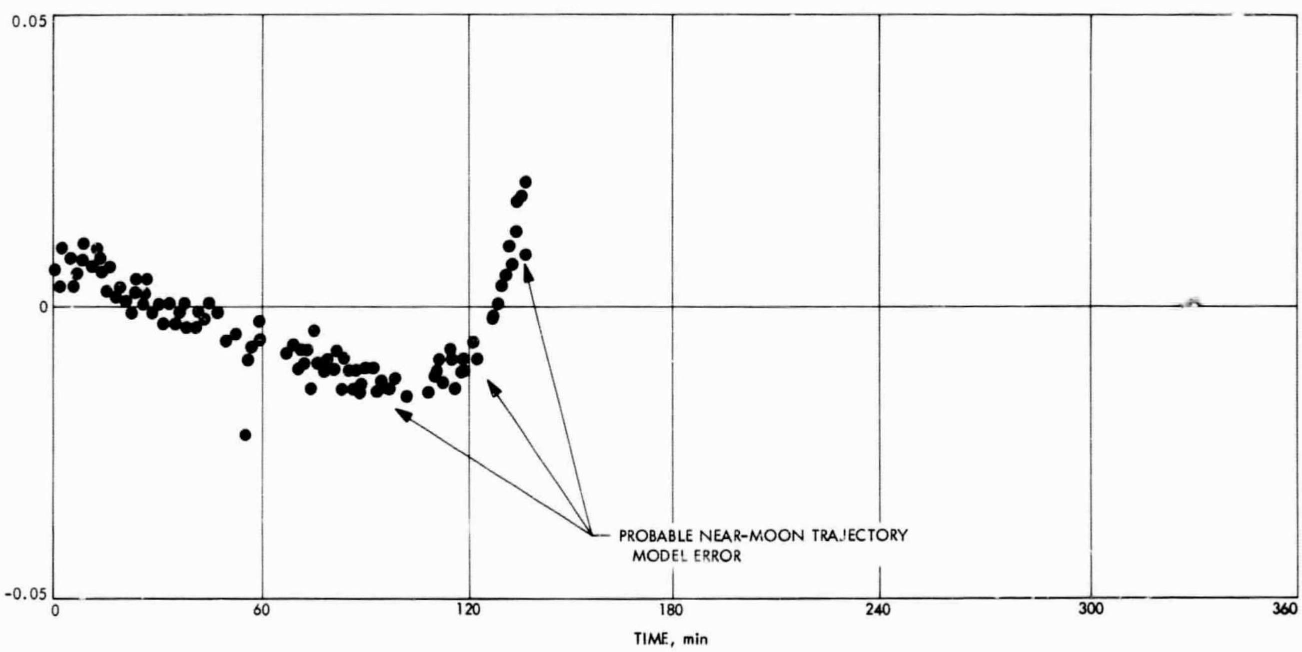


Fig. 71. Third pass two-way (CC3) doppler residuals received by DSS 11 (time from 22:03:00 GMT on January 9, 1968)

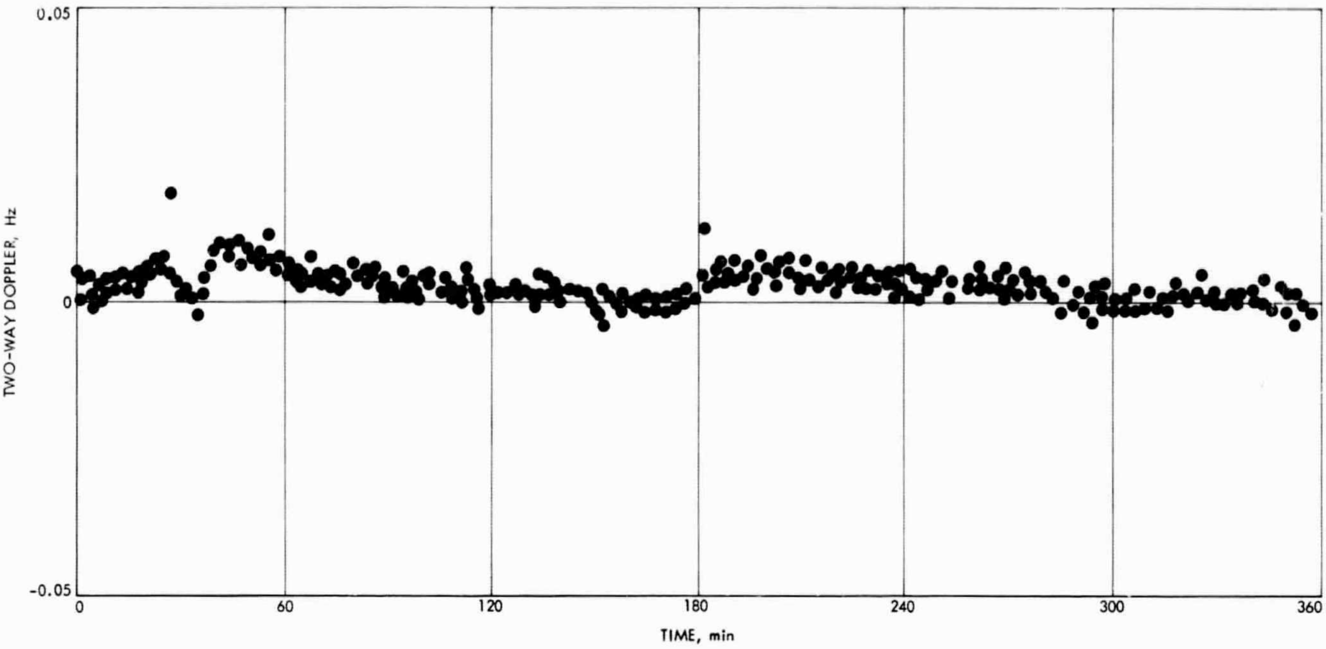


Fig. 72. Second pass two-way (CC3) doppler residuals received by DSS 42 (time from 05:34:00 GMT on January 8, 1968)

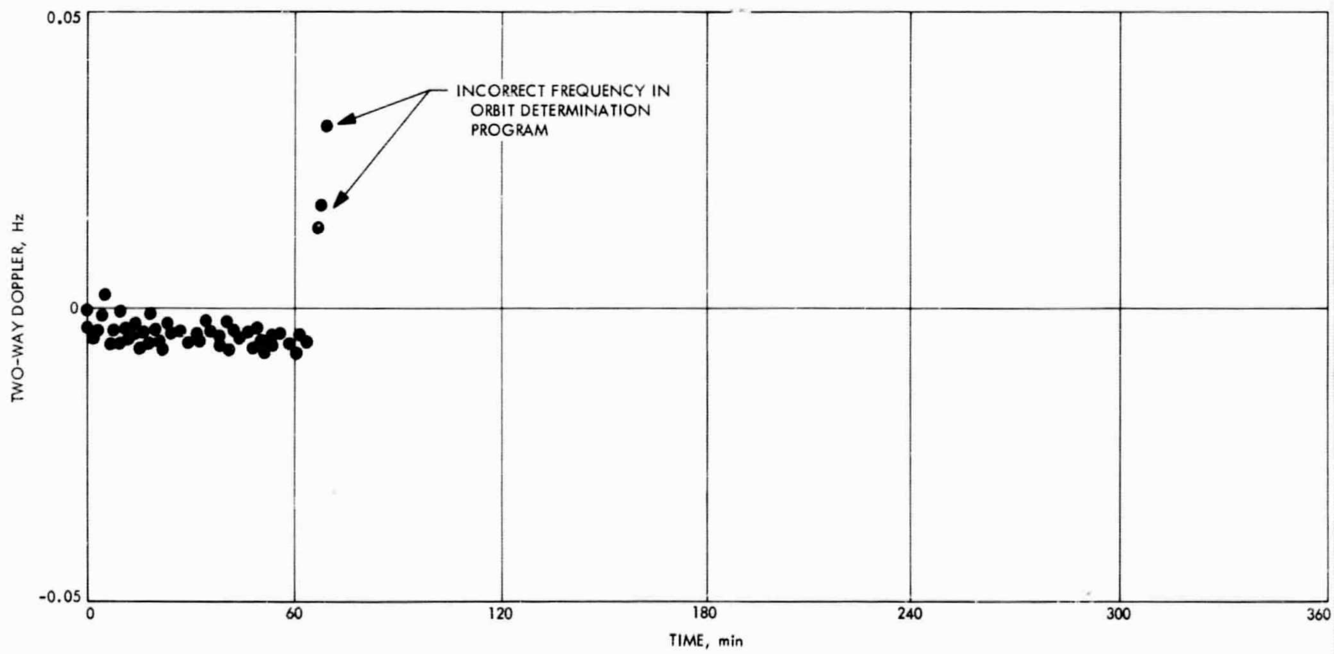


Fig. 73. Second pass two-way (CC3) doppler residuals received by DSS 42 (time from 11:34:00 GMT on January 8, 1968)

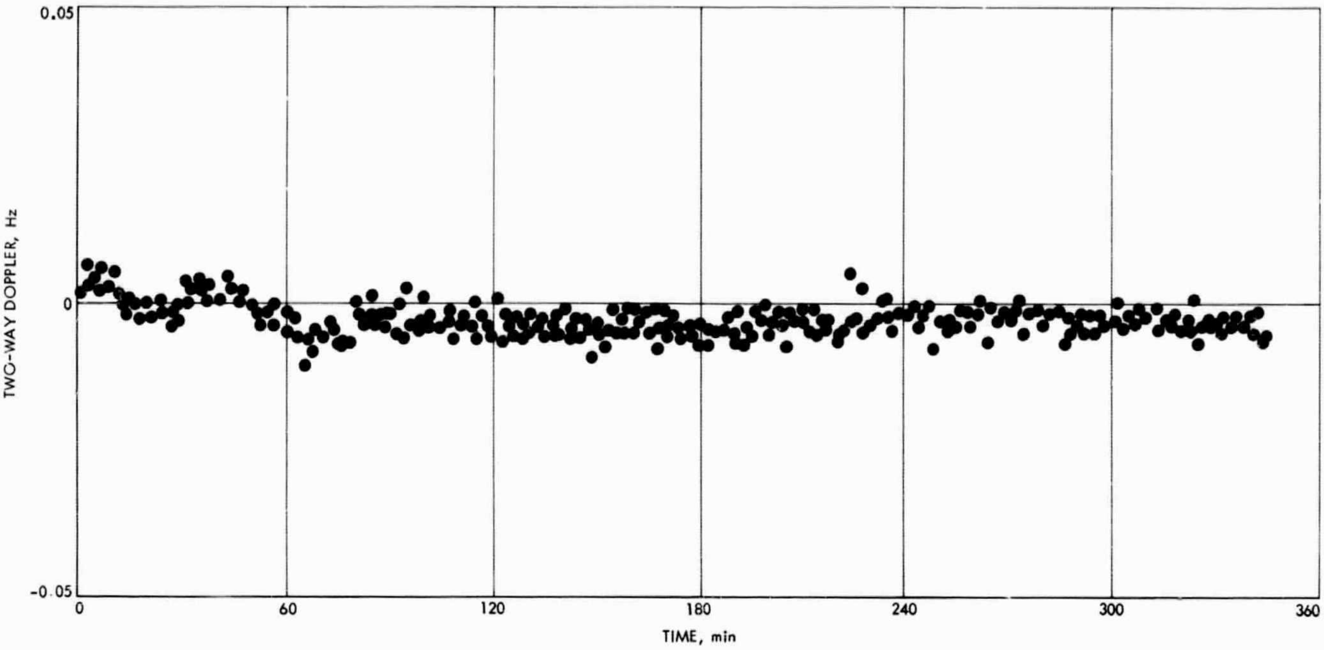


Fig. 74. Third pass two-way (CC3) doppler residuals received by DSS 42 (time from 06:03:00 GMT on January 9, 1968)

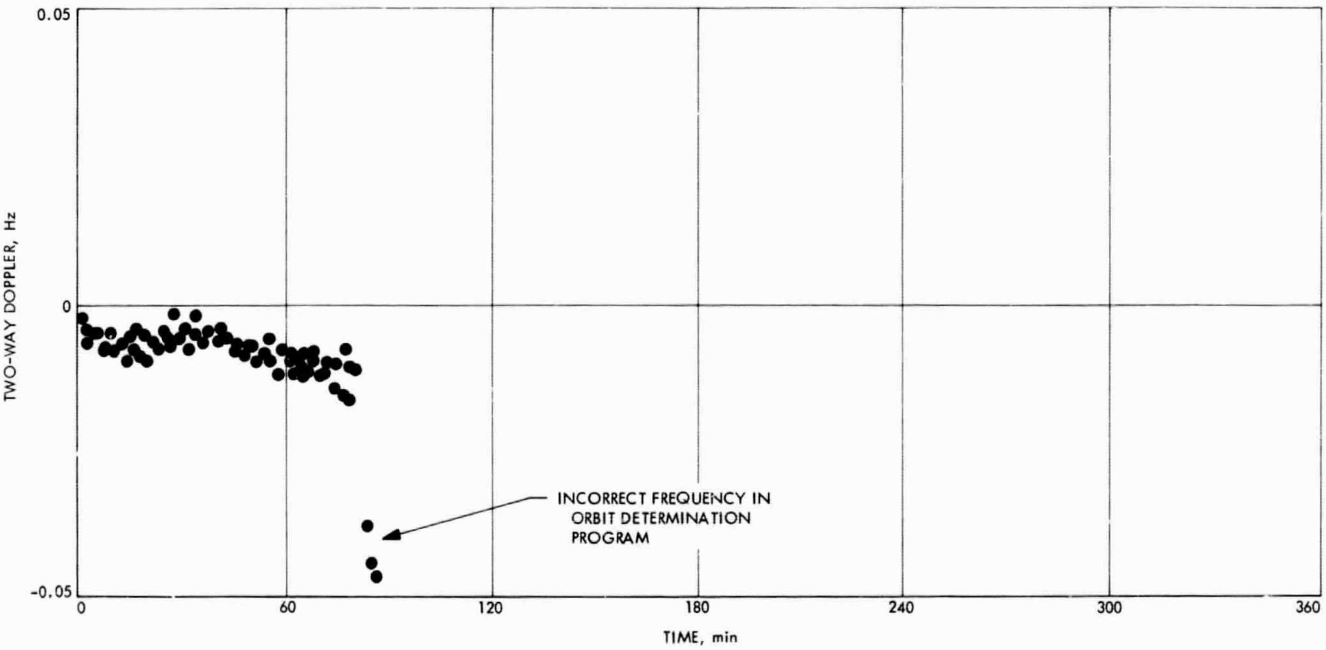


Fig. 75. Third pass two-way (CC3) doppler residuals received by DSS 42 (time from 12:03:00 GMT on January 9, 1968)

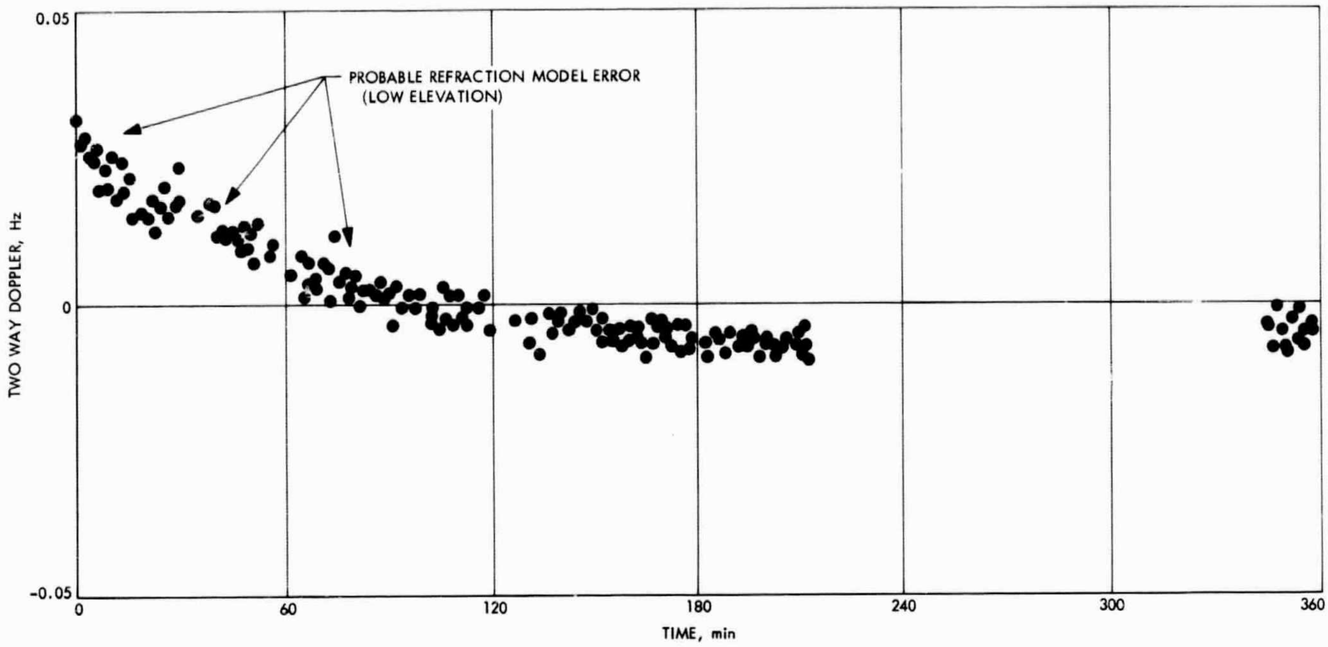


Fig. 76. Second pass two-way (CC3) doppler residuals received by DSS 51 (time from 12:49:00 GMT on January 8, 1968)

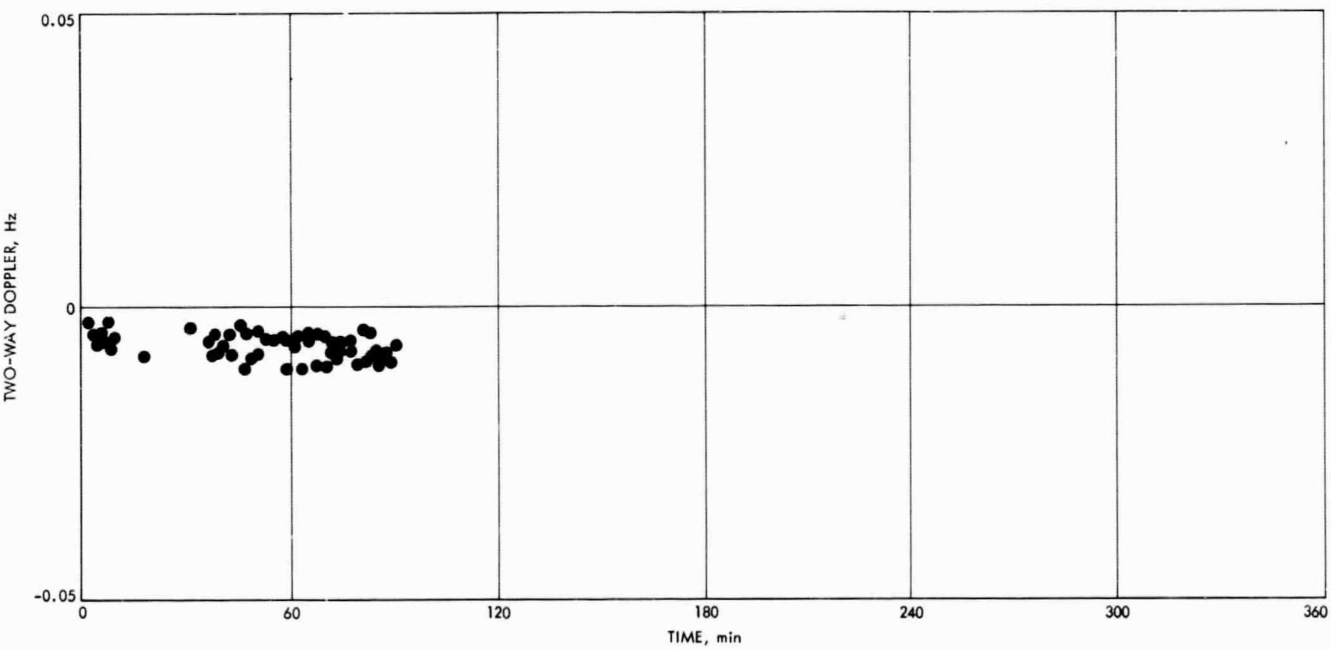


Fig. 77. Second pass two-way (CC3) doppler residuals received by DSS 51 (time from 18:52:00 GMT on January 8, 1968)

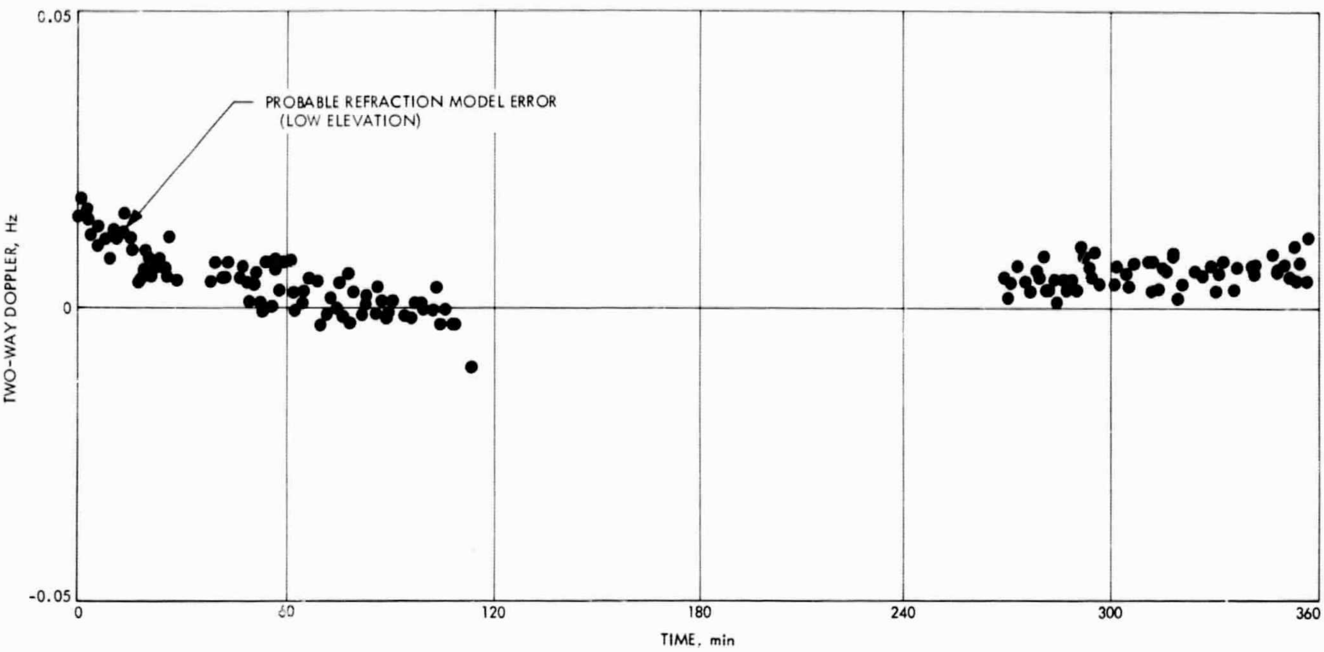


Fig. 78. Third pass two-way (CC3) doppler residuals received by DSS 51 (time from 13:33:00 GMT on January 9, 1968)

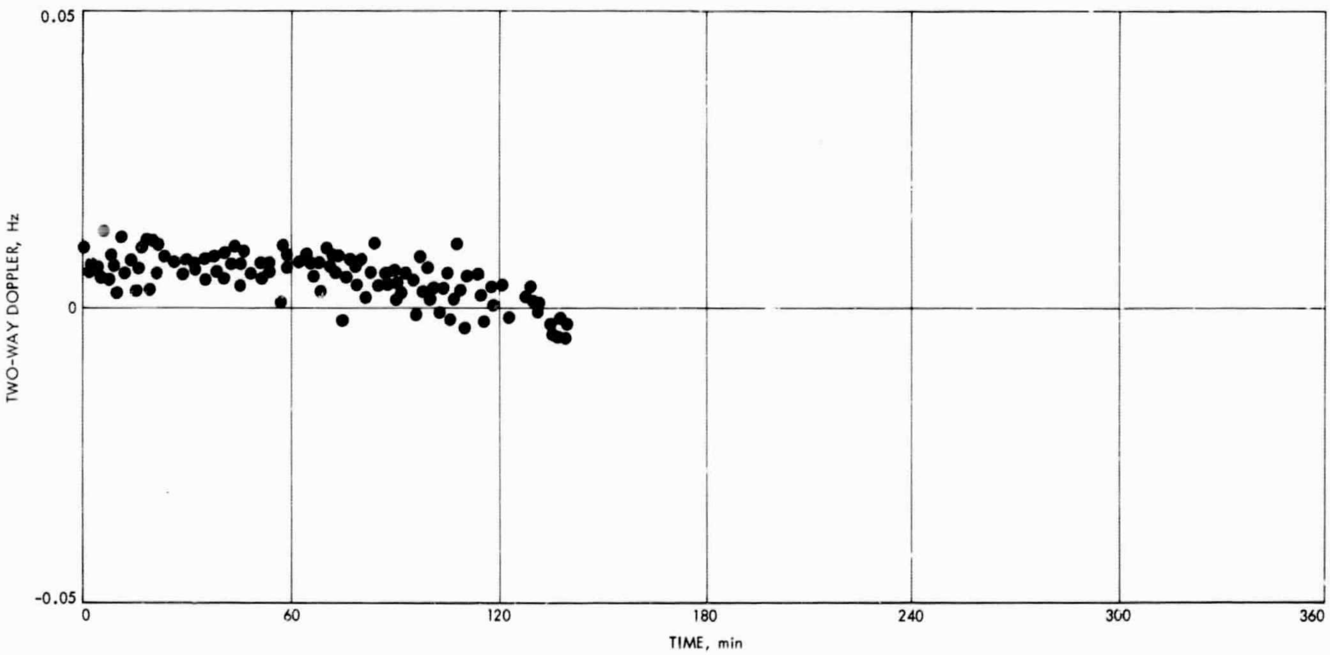


Fig. 79. Third pass two-way (CC3) doppler residuals received by DSS 51 (time from 19:33:00 GMT on January 9, 1968)

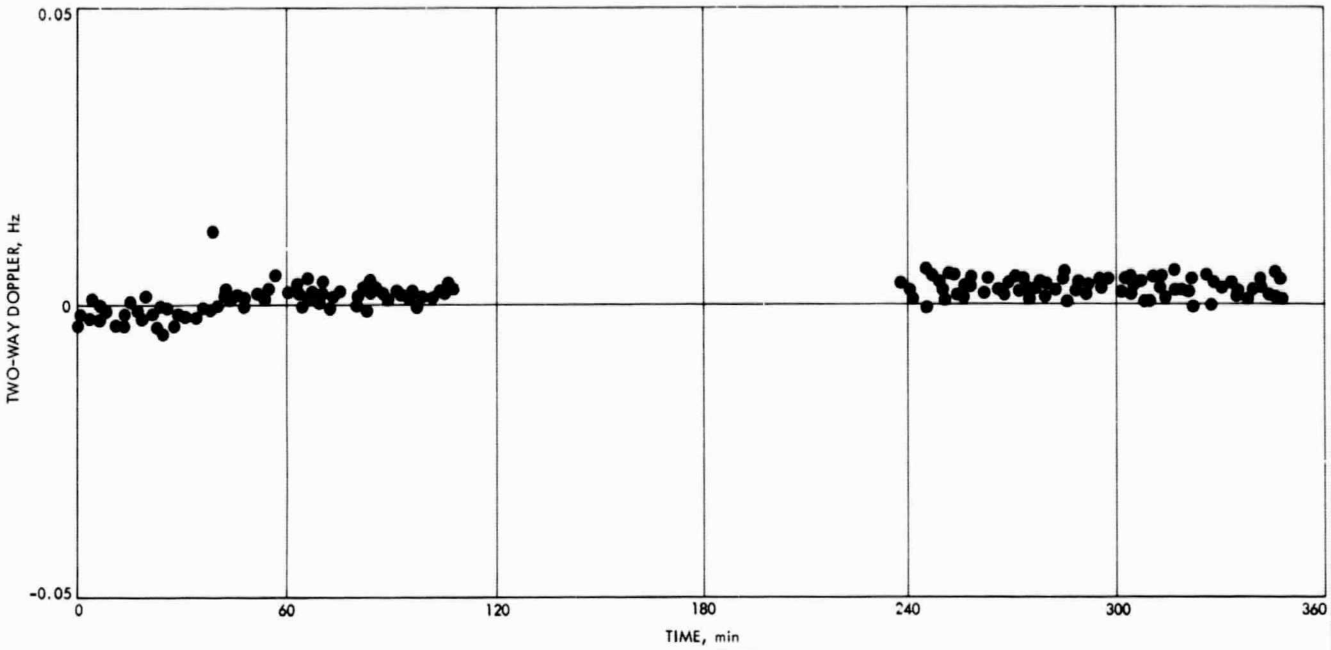


Fig. 80. Second pass two-way (CC3) doppler residuals received by DSS 61 (time from 16:34:00 GMT on January 8, 1968)

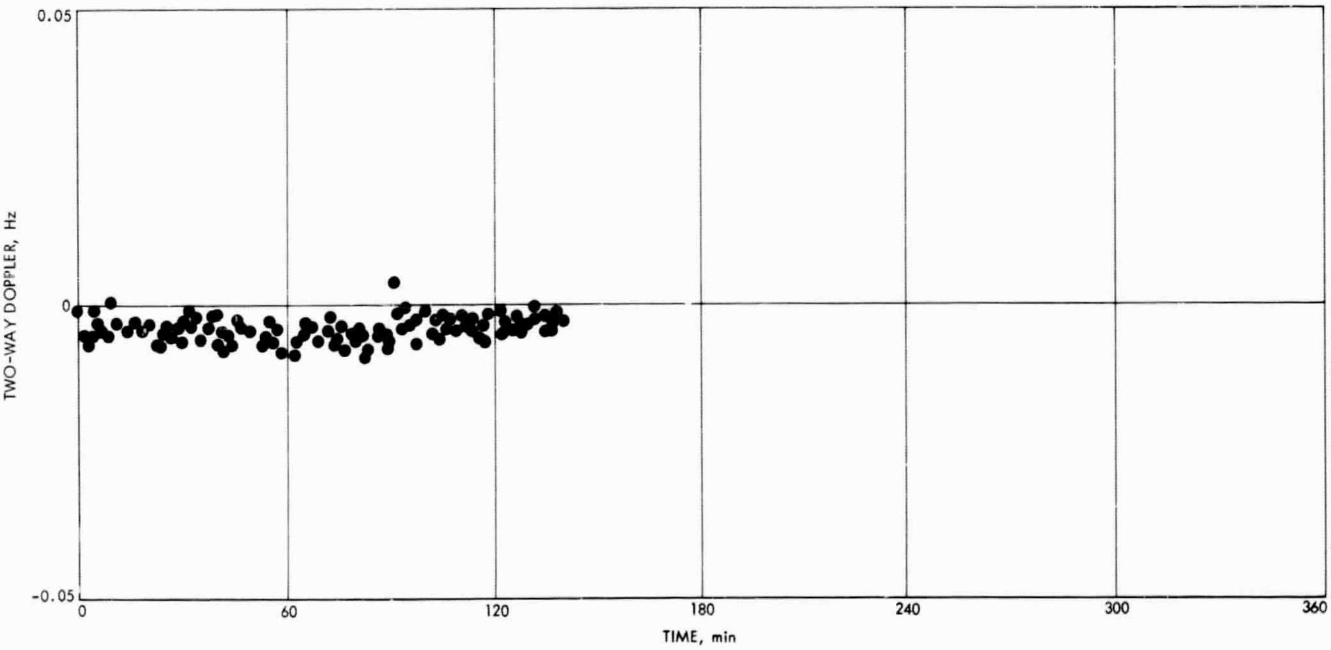


Fig. 81. Third pass two-way (CC3) doppler residuals received by DSS 61 (time from 15:33:00 GMT on January 9, 1968)

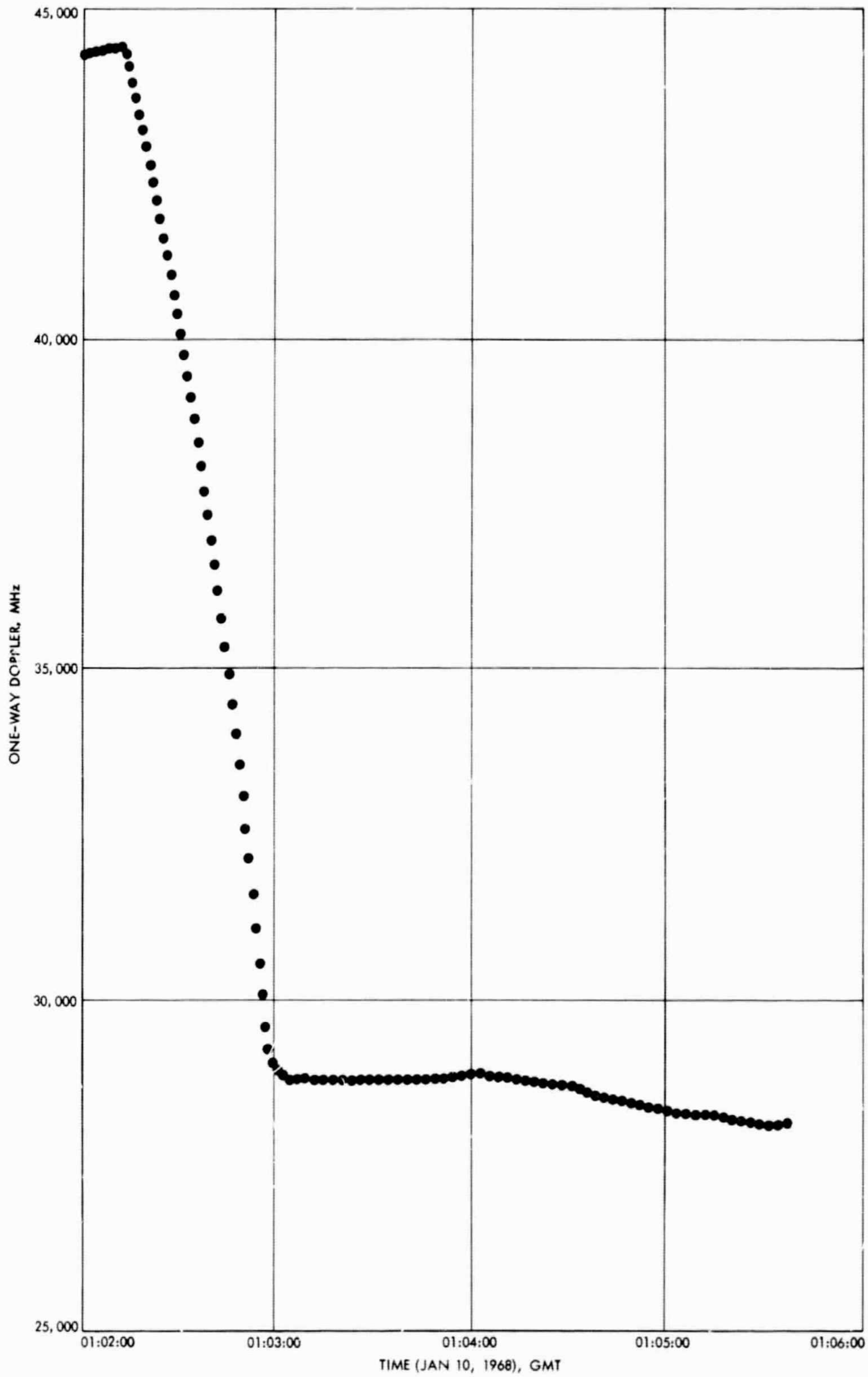


Fig. 82. Retromaneuver phase doppler

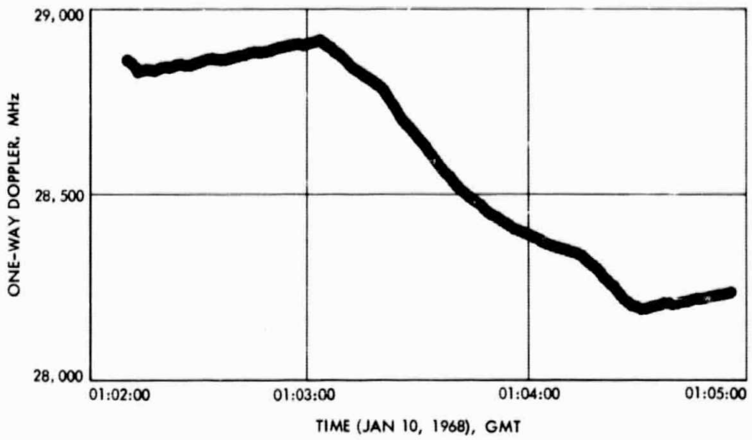


Fig. 83. Vernier phase doppler

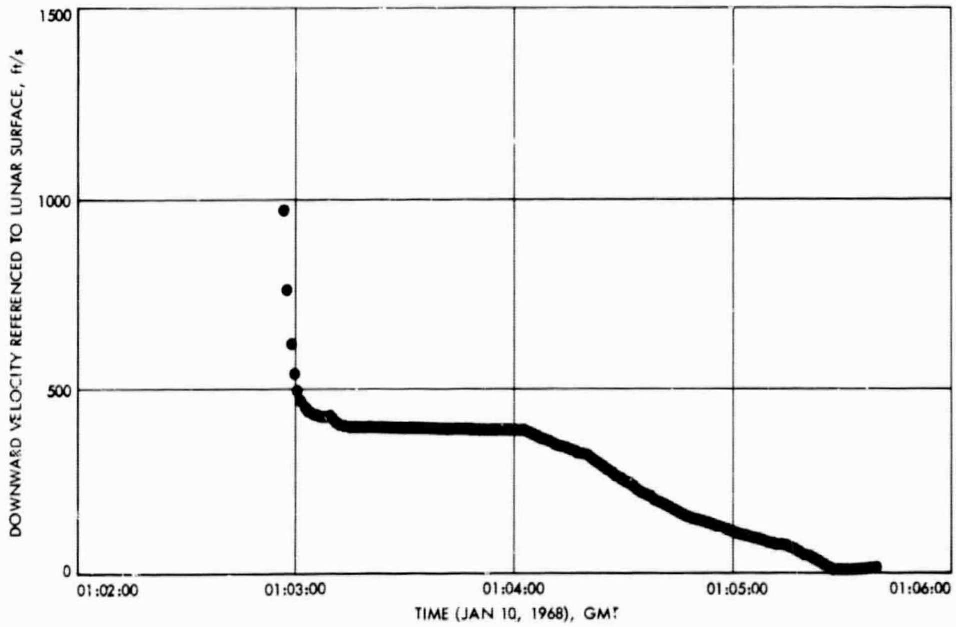


Fig. 84. Vernier phase velocity

Table 44. Transmitter frequency values and range rates

Time, GMT	One-way doppler, frequency, Hz	Difference, Hz	Auxiliary oscillator frequency, Hz	Range rate, km/s
01:00:01.5	1043139.09	8.47	2294991213.02	0.18164503E 01
01:00:02.5	1043147.80	8.71	2294991211.20	0.18173524E 01
01:00:03.5	1043156.16	8.35	2294991209.75	0.18182561E 01
01:00:04.5	1043165.79	9.63	2294991207.06	0.18191614E 01
01:00:05.5	1043175.29	9.50	2294991204.50	0.18200683E 01
01:00:06.5	1043184.02	8.73	2294991202.73	0.18209768E 01
01:00:07.5	1043192.29	8.27	2294991201.44	0.18218869E 01
01:00:08.5	1043201.95	9.66	2294991198.75	0.18227987E 01
01:00:09.5	1043212.22	10.27	2294991195.47	0.18237121E 01
01:00:10.5	1043220.76	8.54	2294991193.94	0.18246271E 01
01:00:11.5	1043230.01	9.25	2294991191.70	0.18255438E 01
01:00:12.5	1043239.09	9.08	2294991189.64	0.18264620E 01
01:00:13.5	1043248.06	8.97	2294991187.72	0.18273820E 01
01:00:14.5	1043257.47	9.41	2294991185.37	0.18283035E 01
01:00:15.5	1043265.55	8.08	2294991184.36	0.18292268E 01
01:00:16.5	1043274.72	9.17	2294991182.28	0.18301516E 01
01:00:17.5	1043284.58	9.87	2294991179.50	0.18310782E 01
01:00:18.5	1043293.65	9.06	2294991177.53	0.18320063E 01
01:00:19.5	1043302.31	8.67	2294991175.98	0.18329362E 01
01:00:20.5	1043311.57	9.26	2294991173.87	0.18338677E 01
01:00:21.5	1043321.02	9.45	2294991171.55	0.18348009E 01
01:00:22.5	1043329.65	8.63	2294991170.09	0.18357357E 01
01:00:23.5	1043338.41	8.76	2294991168.50	0.18366723E 01
01:00:24.5	1043347.51	9.11	2294991166.58	0.18376105E 01
01:00:25.5	1043356.69	9.18	2294991164.59	0.18385504E 01
01:00:26.5	1043366.21	9.52	2294991162.28	0.18394919E 01
01:00:27.5	10433[illegible]5.91	9.70	2294991159.81	0.18404352E 01
01:00:28.5	1043385.07	9.17	2294991157.89	0.18413802E 01
01:00:29.5	1043393.80	8.73	2294991156.39	0.18423268E 01
01:00:30.5	1043402.58	8.78	2294991154.86	0.18432751E 01
01:00:31.5	1043411.82	9.24	2294991152.91	0.18442250E 01
01:00:32.5	1043421.25	9.42	2294991150.77	0.18451766E 01
01:00:33.5	1043431.14	9.89	2294991148.17	0.18461299E 01
01:00:34.5	1043439.67	8.53	2294991146.95	0.18470850E 01
01:00:35.5	1043449.37	9.71	2294991144.58	0.18480417E 01
01:00:36.5	1043458.86	9.49	2294991142.42	0.18490002E 01
01:00:37.5	1043468.26	9.40	2294991140.37	0.18499604E 01
01:00:38.5	1043477.15	8.89	2294991138.84	0.18509224E 01
01:00:39.5	1043487.30	10.16	2294991136.06	0.18518861E 01
01:00:40.5	1043495.78	8.48	2294991135.00	0.18528515E 01
01:00:41.5	1043504.95	9.17	2294991133.22	0.18538187E 01
01:00:42.5	1043513.85	8.91	2294991131.73	0.18547877E 01
01:00:43.5	1043523.29	9.44	2294991129.72	0.18557584E 01
01:00:44.5	1043533.28	9.99	2294991127.19	0.18567309E 01
01:00:45.5	1043543.54	10.26	2294991124.39	0.18577052E 01
01:00:46.5	1043552.67	9.12	2294991122.72	0.18586812E 01
01:00:47.5	1043561.45	8.78	2294991121.42	0.18596590E 01
01:00:48.5	1043571.22	9.77	2294991119.16	0.18606386E 01
01:00:49.5	1043580.51	9.29	2294991117.37	0.18616200E 01
01:00:50.5	1043589.91	9.40	2294991115.52	0.18626031E 01
01:00:51.5	1043599.92	10.01	2294991113.05	0.18635881E 01
01:00:52.5	1043609.77	9.85	2294991110.73	0.18645749E 01
01:00:53.5	1043619.16	9.39	2294991108.91	0.18655635E 01
01:00:54.5	1043628.33	9.18	2294991107.31	0.18665539E 01
01:00:55.5	1043638.28	9.95	2294991104.97	0.18675461E 01
01:00:56.5	1043648.55	10.27	2294991102.31	0.18685401E 01
01:00:57.5	1043657.71	9.16	2294991100.78	0.18695360E 01

Table 44 (contd)

Time, GMT	One-way doppler, frequency, Hz	Difference, Hz	Auxiliary oscillator frequency, Hz	Range rate, km/s
01:00:58.5	1043667.55	9.85	2294991098.58	0.18705337E 01
01:00:59.5	1043678.22	10.67	2294991095.55	0.18715332E 01
01:01:00.5	1043686.97	8.75	2294991094.48	0.18725346E 01
01:01:01.5	1043696.56	9.59	2294991092.56	0.18735377E 01
01:01:02.5	1043706.17	9.61	2294991090.66	0.18745427E 01
01:01:03.5	1043717.52	11.35	2294991087.00	0.18755496E 01
01:01:04.5	1043726.73	9.21	2294991085.52	0.18765583E 01
01:01:05.5	1043735.52	8.79	2294991084.45	0.18775689E 01
01:01:06.5	1043746.21	10.69	2294991081.52	0.18785814E 01
01:01:07.5	1043756.04	9.83	2294991079.45	0.18795957E 01
01:01:08.5	1043766.17	10.13	2294991077.11	0.18806119E 01
01:01:09.5	1043776.08	9.92	2294991074.98	0.18816300E 01
01:01:10.5	1043784.95	8.83	2294991073.97	0.18826500E 01
01:01:11.5	1043795.43	10.51	2294981071.27	0.18836719E 01
01:01:12.5	1043804.84	9.41	2294991069.70	0.18846957E 01
01:01:13.5	1043815.38	10.55	2294991067.02	0.18857214E 01
01:01:14.5	1043825.21	9.82	2294991065.05	0.18867490E 01
01:01:15.5	1043835.29	10.08	2294991062.86	0.18877785E 01
01:01:16.5	1043844.99	9.70	2294991061.05	0.18888100E 01
01:01:17.5	1043855.00	10.01	2294991058.94	0.18898434E 01
01:01:18.5	1043864.37	9.37	2294991057.50	0.18908787E 01
01:01:19.5	1043874.41	10.03	2294991055.41	0.18919160E 01
01:01:20.5	1043884.74	10.33	2294991053.03	0.18929551E 01
01:01:21.5	1043895.01	10.27	2294991050.72	0.18939963E 01
01:01:22.5	1043904.80	9.79	2294991048.92	0.18950994E 01
01:01:23.5	1043914.33	9.53	2294991047.39	0.18960844E 01
01:01:24.5	1043923.82	9.49	2294991045.92	0.18971315E 01
01:01:25.5	1043933.53	9.71	2294991044.23	0.18981805E 01
01:01:26.5	1043944.34	10.81	2294991041.47	0.18992314E 01
01:01:27.5	1043953.98	9.64	2294991039.89	0.19002844E 01
01:01:28.5	1043963.57	9.60	2294991038.39	0.19013393E 01
01:01:29.5	1043973.79	10.22	2294991036.25	0.19023962E 01
01:01:30.5	1043983.23	9.44	2294991034.92	0.19034551E 01
01:01:31.5	1043993.69	10.46	2294991032.59	0.19045159E 01
01:01:32.5	1044003.95	10.26	2294991030.45	0.19055788E 01
01:01:33.5	1044014.19	10.24	2294991028.36	0.19066436E 01
01:01:34.5	1044024.24	10.05	2294991026.48	0.19077105E 01
01:01:35.5	1044033.76	9.52	2294991025.16	0.19087794E 01
01:01:36.5	1044044.00	10.24	2294991023.11	0.19098503E 01
01:01:37.5	1044054.07	10.07	2294991021.23	0.19109233E 01
01:01:38.5	1044064.25	10.16	2294991019.28	0.19119983E 01
01:01:39.5	1044074.80	10.55	2294991016.98	0.19130753E 01
01:01:40.5	1044084.92	10.11	2294991015.14	0.19141544E 01
01:01:41.5	1044094.52	9.60	2294991013.80	0.19152356E 01
01:01:42.5	1044104.79	10.27	2294991011.83	0.19163188E 01
01:01:43.5	1044115.55	10.76	2294991009.39	0.19174040E 01
01:01:44.5	1044125.78	10.23	2294991007.48	0.19184914E 01
01:01:45.5	1044136.63	10.85	2294991004.95	0.19195808E 01
01:01:46.5	1044147.37	10.75	2294991002.58	0.19206723E 01
01:01:47.5	1044157.36	9.98	2294991000.97	0.19217659E 01
01:01:48.5	1044167.55	10.20	2294990999.16	0.19228616E 01
01:01:49.5	1044178.18	10.63	2294990996.94	0.19239594E 01
01:01:50.5	1044188.48	10.30	2294990995.06	0.19250593E 01
01:01:51.5	1044199.76	11.28	2294990992.20	0.19261613E 01
01:01:52.5	1044210.58	10.82	2294990989.83	0.19272654E 01
01:01:53.5	1044220.67	10.09	2294990988.23	0.19283717E 01

Table 44 (contd)

Time, GMT	One-way doppler, frequency, Hz	Difference, Hz	Auxiliary oscillator frequency, Hz	Range rate, km/s
01:01:54.5	1044231.21	10.54	2294990986.17	0.19294801E 01
01:01:55.5	1044241.21	10.00	2294990984.67	0.19305906E 01
01:01:56.5	1044250.56	9.36	2294990983.83	0.19317032E 01
01:01:57.5	1044261.21	10.64	2294990981.72	0.19328180E 01
01:01:58.5	1044272.33	11.13	2294990979.14	0.19339349E 01
01:01:59.5	1044283.09	10.76	2294990976.94	0.19350540E 01
01:02:00.5	1044293.25	10.16	2294990975.37	0.19361753E 01
01:02:01.5	1044303.62	10.37	2294990973.61	0.19372987E 01
01:02:02.5	1044314.58	10.96	2294990971.25	0.19384243E 01
01:02:03.5	1044325.17	10.59	2294990969.30	0.19395521E 01
01:02:04.5	1044335.77	10.60	2294990967.36	0.19406821E 01
01:02:05.5	1044346.31	10.54	2294990965.48	0.19418142E 01
01:02:06.5	1044356.17	9.86	2294990964.31	0.19429486E 01
01:02:07.5	1044367.32	11.16	2294990961.86	0.19440851E 01
01:02:08.5	1044377.75	10.43	2294990960.16	0.19452239E 01
01:02:09.5	1044388.92	11.17	2294990957.70	0.19463648E 01
01:02:10.5	1044399.36	10.44	2294990956.03	0.19475080E 01
01:02:11.5	1044409.64	10.29	2294990954.52	0.19486534E 01
01:02:12.5	1044420.66	11.01	2294990952.30	0.19498010E 01
01:02:13.5	1044431.72	11.07	2294990950.02	0.19509509E 01
01:02:14.5	1044442.91	11.19	2294990947.66	0.19521030E 01
01:02:14.5	1044442.91	11.19	2294990950.31[a]	0.19524484E 01
01:02:15.5	1044449.52	6.61	2294990948.37	0.19530614E 01
01:02:16.5	1044338.22	−111.30	2294990946.45	4.19382701E 01
01:02:17.5	1044131.90	−206.32	2294990944.53	0.19110674E 01
01:02:18.5	1043918.71	−213.19	2294990942.61	0.18829682E 01
01:02:19.5	1043695.41	−223.30	2294990940.67	0.18535428E 01
01:02:20.5	1043458.73	−236.68	2294990938.75	0.18223767E 01
01:02:21.5	1043209.46	−249.27	2294990936.83	0.17895637E 01
01:02:22.5	1042950.62	−258.83	2294990934.89	0.17554987E 01
01:02:23.5	1042686.36	−264.26	2294990932.97	0.17207291E 01
01:02:24.5	1042418.04	−268.32	2294990931.05	0.16854252E 01
01:02:25.5	1042145.38	−272.67	2294990929.12	0.16495584E 01
01:02:26.5	1041870.14	−275.24	2294990927.19	0.16133492E 01
01:02:27.5	1041592.87	−277.26	2294990925.27	0.15768804E 01
01:02:28.5	1041312.03	−280.84	2294990923.36	0.15399470E 01
01:02:29.5	1041027.50	−284.53	2294990921.42	0.15025229E 01
01:02:30.5	1040738.57	−288.93	2294990919.50	0.14645294E 01
01:02:31.5	1040442.12	−296.45	2294990917.58	0.14255543E 01
01:02:32.5	1040137.35	−304.77	2294990915.67	0.13854930E 01
01:02:33.5	1039824.78	−312.57	2294990913.73	0.13444108E 01
01:02:34.5	1039505.19	−319.59	2294990911.81	0.13024103E 01
01:02:35.5	1039178.23	−326.96	2294990909.91	0.12594500E 01
01:02:36.5	1038842.26	−335.97	2294990907.97	0.12153097E 01
01:02:37.5	1038498.34	−343.92	2294990906.06	0.11701354E 01
01:02:38.5	1038144.24	−354.10	2294990904.14	0.11236284E 01
01:02:39.5	1037781.10	−363.13	2294990902.23	0.10759435E 01
01:02:40.5	1037409.65	−371.46	2294990900.30	0.10271679E 01
01:02:41.5	1037028.91	−380.74	2294990898.39	0.97718397E 00
01:02:42.5	1036639.61	−389.30	2294990896.47	0.92607882E 00
01:02:43.5	1036241.77	−397.84	2294990894.56	0.87386122E 00
01:02:44.5	1035834.70	−407.07	2294990892.62	0.82043083E 00
01:02:45.5	1035418.82	−415.88	2294990890.72	0.76585744E 00
01:02:46.5	1034993.39	−425.43	2294990888.81	0.71003419E 00
01:02:47.5	1034556.97	−436.42	2294990886.87	0.65277347E 00
01:02:48.5	1034109.58	−447.39	2294990884.97	0.59407966E 00

[a]Values from this point on are extrapolated.

Table 44 (contd)

Time, GMT	One-way doppler, frequency, Hz	Difference, Hz	Auxiliary oscillator frequency, Hz	Range rate, km/s
01:02:49.5	1033651.02	−458.56	2294990883.06	0.53393093E 00
01:02:50.5	1033181.01	−470.01	2294990881.16	0.47228367E 00
01:02:51.5	1032698.53	−482.48	2294990879.22	0.40900480E 00
01:02:52.5	1032201.88	−496.65	2294990877.31	0.34388058E 00
01:02:53.5	1031690.91	−510.97	2294990875.41	0.27688264E 00
01:02:54.5	1031168.35	−522.56	2294990873.48	0.20837090E 00
01:02:55.5	1030650.71	−517.64	2294990871.58	0.14050263E 00
01:02:56.5	1030137.70	−513.01	2294990869.67	0.73238574E −01
01:02:57.5	1029654.35	−483.35	2294990867.77	0.98506493E 02
01:02:58.5	1029314.10	−340.25	2294990865.84	−0.34845908E −01
01:02:59.5	1029132.71	−181.39	2294990863.92	−0.58791973E −01
01:03:00.5	1029030.92	−101.79	2294990862.02	−0.72339888E −01
01:03:01.5	1028968.56	−62.36	2294990860.11	−0.80733444E −01
01:03:02.5	1028930.73	−37.82	2294990858.20	−0.85924884E −01
01:03:03.5	1028909.59	−21.14	2294990856.30	−0.88935047E −01
01:03:04.5	1028898.64	−10.95	2294990854.39	−0.90614631E −01
01:03:05.5	1028891.27	−7.37	2294990852.47	−0.91827421E −01
01:03:06.5	1028885.90	−5.37	2294990850.56	−0.92778458E −01
01:03:07.5	1028882.08	−3.81	2294990848.66	−0.93524455E −01
01:03:08.5	1028878.43	−3.65	2294990846.75	−0.94253002E −01
01:03:09.5	1028871.49	−6.95	2294990844.84	−0.95406898E −01
01:03:10.5	1028862.54	−8.95	2294990842.94	−0.96826909E −01
01:03:11.5	1028853.87	−8.67	2294990841.03	−0.98207658E −01
01:03:12.5	1028843.15	−10.71	2294990839.12	−0.99856704E −01
01:03:13.5	1028833.63	−9.52	2294990837.22	−0.10134870E 00
01:03:14.5	1028834.12	.49	2294990835.31	−0.10153411E 00
01:03:15.5	1028836.17	2.05	2294990833.42	−0.10151229E 00
01:03:16.5	1028837.46	1.29	2294990831.50	−0.10159518E 00
01:03:17.5	1028838.15	.68	2294990829.59	−0.10175442E 00
01:03:18.5	1028840.05	1.91	2294990827.70	−0.10175223E 00
01:03:19.5	1028841.95	1.90	2294990825.78	−0.10175660E 00
01:03:20.5	1028843.71	1.76	2294990823.89	−0.10177405E 00
01:03:21.5	1028844.61	.90	2294990821.98	−0.10190710E 00
01:03:22.5	1028845.60	.99	2294990820.09	−0.10202271E 00
01:03:23.5	1028847.84	2.24	2294990818.19	−0.10197909E 00
01:03:24.5	1028850.57	2.72	2294990816.28	−0.10187220E 00
01:03:25.5	1028851.72	1.15	2294990814.39	−0.10196818E 00
01:03:26.5	1028852.91	1.19	2294990812.48	−0.10206198E 00
01:03:27.5	1028855.21	2.30	2294990810.58	−0.10200962E 00
01:03:28.5	1028856.20	.99	2294990808.69	−0.10212959E 00
01:03:29.5	1028857.87	1.67	2294990806.80	−0.10215795E 00
01:03:30.5	1028859.73	1.87	2294990804.87	−0.10216450E 00
01:03:31.5	1028861.45	1.72	2294990802.98	−0.10218849E 00
01:03:32.5	1028862.85	1.39	2294990801.09	−0.10225175E 00
01:03:33.5	1028864.21	1.36	2294990799.20	−0.10231937E 00
01:03:34.5	1028865.09	.89	2294990797.30	−0.10245461E 00
01:03:35.5	1028866.83	1.73	2294990795.41	−0.10247642E 00
01:03:36.5	1028868.81	1.99	2294990793.52	−0.10246115E 00
01:03:37.5	1028870.80	1.99	2294990791.61	−0.10245024E 00
01:03:38.5	1028872.01	1.21	2294990789.70	−0.10254186E 00
01:03:39.5	1028873.72	1.71	2294990787.81	−0.10256585E 00
01:03:40.5	1028876.65	2.93	2294990785.92	−0.10243061E 00
01:03:41.5	1028877.89	1.24	2294990784.03	−0.10251568E 00
01:03:42.5	1028880.63	2.74	2294990782.14	−0.10240444E 00
01:03:43.5	1028882.17	1.54	2294990780.25	−0.10245024E 00
01:03:44.5	1028883.05	.88	2294990778.34	−0.10258330E 00

Table 44 (contd)

Time, GMT	One-way doppler, frequency, Hz	Difference, Hz	Auxiliary oscillator frequency, Hz	Range rate, km/s
01:03:45.5	1028884.96	1.91	2294990776.45	−0.10258112E 00
01:03:46.5	1028886.32	1.36	2294990774.56	−0.10265092E 00
01:03:47.5	1028887.52	1.20	2294990772.67	−0.10274035E 00
01:03:48.5	1028890.05	2.54	2294990770.77	−0.10265965E 00
01:03:49.5	1028891.80	1.75	2294990768.89	−0.10267491E 00
01:03:50.5	1028893.90	2.09	2294990767.00	−0.10264874E 00
01:03:51.5	1028895.27	1.37	2294990765.09	−0.10271854E 00
01:03:52.5	1028896.82	1.55	2294990763.22	−0.10276217E 00
01:03:53.5	1028898.62	1.80	2294990761.33	−0.10277307E 00
01:03:54.5	1028899.61	.99	2294990759.44	−0.10289086E 00
01:03:55.5	1028900.79	1.18	2294990757.55	−0.10298466E 00
01:03:56.5	1028902.24	1.45	2294990755.66	−0.10304137E 00
01:03:57.5	1028904.57	2.33	2294990753.78	−0.10298247E 00
01:03:58.5	1028905.96	1.39	2294990751.89	−0.10304791E 00
01:03:59.5	1028908.15	2.20	2294990750.00	−0.10300865E 00
01:04:00.5	1028909.22	1.06	2294990748.11	−0.10311553E 00
01:04:01.5	1028911.81	2.59	2294990746.23	−0.10301956E 00
01:04:02.5	1028914.29	2.48	2294990744.33	−0.10294757E 00
01:04:03.5	1028914.67	.38	2294990742.45	−0.10314389E 00
01:04:04.5	1028905.48	−9.19	2294990740.56	−0.10459008E 00
01:04:05.5	1028897.72	−7.76	2294990738.69	−0.10584649E 00
01:04:06.5	1028889.92	−7.80	2294990736.80	−0.10717600E 00
01:04:07.5	1028882.34	−7.58	2294990734.91	−0.10835278E 00
01:04:08.5	1028871.07	−11.27	2294990733.03	−0.11006726E 00
01:04:09.5	1028866.25	−4.83	2294990731.14	−0.11094632E 00
01:04:10.5	1028857.07	−9.17	2294990729.27	−0.11238814E 00
01:04:11.5	1028848.77	−8.30	2294990727.37	−0.11372090E 00
01:04:12.5	1028841.91	−6.87	2294990725.50	−0.11486171E 00
01:04:13.5	1028833.66	−8.25	2294990723.61	−0.11618575E 00
01:04:14.5	1028825.91	−7.75	2294990721.73	−0.11744216E 00
01:04:15.5	1028818.47	−7.44	2294990719.86	−0.11866150E 00
01:04:16.5	1028811.79	−6.67	2294990717.97	−0.11978049E 00
01:04:17.5	1028804.30	−7.50	2294990716.09	−0.12100201E 00
01:04:18.5	1028797.47	−6.83	2294990714.22	−0.12213845E 00
01:04:19.5	1028789.02	−8.45	2294990712.34	−0.12348866E 00
01:04:20.5	1028780.04	−8.98	2294990710.45	−0.12490868E 00
01:04:21.5	1028766.77	−13.27	2294990708.58	−0.12688709E 00
01:04:22.5	1028754.91	−11.87	2294990706.70	−0.12868010E 00
01:04:23.5	1028742.02	−12.89	2294990704.83	−0.13061054E 00
01:04:24.5	1028728.86	−13.16	2294990702.94	−0.13257805E 00
01:04:25.5	1028716.46	−12.39	2294990701.06	−0.13444086E 00
01:04:26.5	1028704.21	−12.26	2294990699.19	−0.13628622E 00
01:04:27.5	1028691.50	−12.70	2294990697.30	−0.13819266E 00
01:04:28.5	1028679.08	−12.42	2294990695.44	−0.14005765E 00
01:04:29.5	1028666.35	−12.73	2294990693.56	−0.14196627E 00
01:04:30.5	1028653.06	−13.29	2294990691.69	−0.14394905E 00
01:04:31.5	1028640.89	−12.17	2294990689.80	−0.14578568E 00
01:04:32.5	1028628.48	−12.40	2294990687.94	−0.14764849E 00
01:04:33.5	1028615.75	−12.73	2294990686.06	−0.14955493E 00
01:04:34.5	1028603.37	−12.38	2294990684.19	−0.15141774E 00
01:04:35.5	1028590.69	−12.68	2294990682.31	−0.15331982E 00
01:04:36.5	1028578.15	−12.54	2294990680.44	−0.15520226E 00
01:04:37.5	1028565.02	−13.13	2294990678.58	−0.15716105E 00
01:04:38.5	1028551.54	−13.48	2294990676.69	−0.15916782E 00
01:04:39.5	1028539.78	−11.76	2294990674.83	−0.16094556E 00
01.04.40.5	1028528.44	−11.34	2294990672.95	−0.16267313E 00

Table 44 (contd)

Time, GMT	One-way doppler, frequency, Hz	Difference, Hz	Auxiliary oscillator frequency, Hz	Range rate, km/s
01:04:41.5	1028518.29	−10.16	2294990671.08	−0.16424365E 00
01:04:42.5	1028510.44	−7.84	2294990669.20	−0.16551534E 00
01:04:43.5	1028501.79	−8.65	2294990667.34	−0.16688736E 00
01:04:44.5	1028493.93	−7.86	2294990665.48	−0.16815687E 00
01:04:45.5	1028486.33	−7.60	2294990663.59	−0.16939583E 00
01:04:46.5	1028477.42	−8.91	2294990661.73	−0.17080494E 00
01:04:47.5	1028469.92	−7.50	2294990659.87	−0.17202645E 00
01:04:48.5	1028461.64	−8.28	2294990657.98	−0.17335703E 00
01:04:49.5	1028455.77	−5.87	2294990656.12	−0.17436478E 00
01:04:50.5	1028448.55	−7.22	2294990654.27	−0.17554922E 00
01:04:51.5	1028443.09	−5.45	2294990652.41	−0.17650680E 00
01:04:52.5	1028436.11	−6.98	2294990650.52	−0.17766505E 00
01:04:53.5	1028430.27	−5.85	2294990648.66	−0.17867062E 00
01:04:54.5	1028423.61	−6.66	2294990646.80	−0.17978526E 00
01:04:55.5	1028418.39	−5.22	2294990644.94	−0.18070794E 00
01:04:56.5	1028413.42	−4.97	2294990643.06	−0.18160226E 00
01:04:57.5	1028407.24	−6.19	2294990641.20	−0.18265364E 00
01:04:58.5	1028402.59	−4.65	2294990639.34	−0.18350433E 00
01:04:59.5	1028398.08	−4.51	2294990637.47	−0.18433758E 00
01:05:00.5	1028392.38	−5.70	2294990635.61	−0.18532570E 00
01:05:01.5	1028386.85	−5.53	2294990633.75	−0.18628983E 00
01:05:02.5	1028381.60	−5.25	2294990631.89	−0.18721905E 00
01:05:03.5	1028377.99	−3.61	2294990630.02	−0.18793451E 00
01:05:04.5	1028374.55	−3.44	2294990628.16	−0.18863034E 00
01:05:05.5	1028368.74	−5.80	2294990626.30	−0.18962936E 00
01:05:06.5	1028365.88	−2.87	2294990624.44	−0.19024666E 00
01:05:07.5	1028361.33	−4.55	2294990622.58	−0.19108209E 00
01:05:08.5	1028358.67	−2.66	2294990620.72	−0.19167540E 00
01:05:09.5	1028355.42	−3.25	2294990618.86	−0.19234287E 00
01:05:10.5	1028350.42	−5.00	2294990617.00	−0.19323719E 00
01:05:11.5	1028348.07	−2.35	2294990615.14	−0.19378688E 00
01:05:12.5	1028344.89	−3.18	2294990613.28	−0.19444344E 00
01:05:13.5	1028342.58	−2.32	2294990611.42	−0.19498876E 00
01:05:14.5	1028339.65	−2.93	2294990609.56	−0.19561697E 00
01:05:15.5	1028329.56	−10.10	2294990607.70	−0.19717658E 00
01:05:16.5	1028318.50	−11.06	2294990605.86	−0.19886271E 00
01:05:17.5	1028308.24	−10.26	2294990603.98	−0.20044632E 00
01:05:18.5	1028299.91	−8.33	2294990602.14	−0.20177690E 00
01:05:19.5	1028291.48	−8.42	2294990600.28	−0.20312056E 00
01:05:20.5	1028284.13	−7.36	2294990598.44	−0.20432027E 00
01:05:21.5	1028277.81	−6.31	2294990596.56	−0.20539345E 00
01:05:22.5	1028268.83	−8.99	2294990594.72	−0.20680692E 00
01:05:23.5	1028257.23	−11.60	2294990592.86	−0.20856503E 00
01:05:24.5	1028245.70	−11.52	2294990591.00	−0.21031442E 00
01:05:25.5	1028233.02	−12.68	2294990589.16	−0.21220995E 00
01:05:26.5	1028222.26	−10.76	2294990587.30	−0.21385899E 00
01:05:27.5	1028212.00	−10.26	2294990585.45	−0.21543824E 00
01:05:28.5	1028208.49	−3.51	2294990583.59	−0.21614061E 00
01:05:29.5	1028205.73	−2.75	2294990581.75	−0.21674264E 00
01:05:30.5	1028202.47	−3.26	2294990579.89	−0.21741011E 00
01:05:31.5	1028200.32	−2.15	2294990578.03	−0.21793580E 00
01:05:32.5	1028201.51	1.19	2294990576.19	−0.21802087E 00
01:05:33.5	1028204.19	2.68	2294990574.34	−0.21791181E 00
01:05:34.5	1028206.24	2.05	2294990572.50	−0.21788345E 00
01:05:35.5	1028207.62	1.38	2294990570.64	−0.21794671E 00
01:05:36.5	1028211.14	3.52	2294990568.80	−0.21772640E 00
01:05:37.5	1028214.81	3.67	2294990566.95	−0.21748864E 00

Table 44 (contd)

Time, GMT	One-way doppler, frequency, Hz	Difference, Hz	Auxiliary oscillator frequency, Hz	Range rate, km/s
01:05:38.5	1028202.80	−12.01	2294990565.08	−0.21930346E 00
01:05:39.5	1028208.13	5.33	2294990563.23	−0.21884757E 00
01:05:40.5	1028209.23	1.09	2294990561.41	−0.21894355E 00
01:05:41.5	1028211.08	1.86	2294990559.56	−0.21894137E 00
01:05:42.5	1028212.93	1.85	2294990557.70	−0.21894355E 00
01:05:43.5	1028214.24	1.31	2294990555.86	−0.21901335E 00
01:05:44.5	1028216.55	2.31	2294990554.02	−0.21895228E 00
01:05:45.5	1028217.96	1.41	2294990552.17	−0.21900899E 00
01:05:46.5	1028220.14	2.19	2294990550.31	−0.21896536E 00
01:05:47.5	1028221.48	1.34	2294990548.47	−0.21903298E 00
01:05:48.5	1028223.20	1.71	2294990546.64	−0.21904825E 00
01:05:49.5	1028225.11	1.92	2294990544.78	−0.21903953E 00
01:05:50.5	1028226.74	1.63	2294990542.94	−0.21906788E 00
01:05:51.5	1028228.68	1.94	2294990541.09	−0.21905480E 00
01:05:52.5	1028230.81	2.13	2294990539.27	−0.21901553E 00
01:05:53.5	1028232.58	1.76	2294990537.41	−0.21902644E 00
01:05:54.5	1028234.28	1.70	2294990535.58	−0.21904607E 00
01:05:55.5	1028236.85	2.57	2294990533.73	−0.21895009E 00
01:05:56.5	1028238.07	1.23	2294990531.87	−0.21903298E 00
01:05:57.5	1028239.46	1.39	2294990530.05	−0.21908970E 00
01:05:58.5	1028241.25	1.78	2294990528.20	−0.21909842E 00
01:05:59.5	1028243.86	2.61	2294990526.37	−0.21899590E 00
01:06:00.5	1028245.89	2.03	2294990524.52	−0.21897409E 00
01:06:01.5	1028248.39	2.51	2294990522.69	−0.21888466E 00
01:06:02.5	1028250.63	2.23	2294990520.84	−0.21883230E 00
01:06:03.5	1028252.16	1.54	2294990519.00	−0.21887375E 00
01:06:04.5	1028253.94	1.77	2294990517.17	−0.21888029E 00
01:06:05.5	1028255.43	1.50	2294990515.33	−0.21892828E 00
01:06:06.5	1028257.30	1.86	2294990513.50	−0.21892174E 00
01:06:07.5	1028259.51	2.21	2294990511.66	−0.21887375E 00
01:06:08.5	1028260.38	0.87	2294990509.81	−0.21900026E 00
01:06:09.5	1028261.99	1.61	2294990507.98	−0.21902862E 00
01:06:10.5	1028265.38	3.39	2294990506.16	−0.21882576E 00
01:06:11.5	1028267.12	1.74	2294990504.31	−0.21883885E 00
01:06:12.5	1028269.06	1.94	2294990502.48	−0.21882576E 00
01:06:13.5	1028270.71	1.65	2294990500.66	−0.21884757E 00
01:06:14.5	1028272.93	2.22	2294990498.80	−0.21880177E 00

Table 45. DSS 11 actual doppler, hypothetical doppler, and range rates

Time, GMT	Doppler frequency, Hz	Hypothetical doppler frequency at lunar surface, Hz	Difference, Hz	Velocity referenced to lunar surface, ft/s
01:02:00.5	1044293.25	1027739.88	16553.37	7094.28
01:02:01.5	1044303.62	1027742.11	16561.51	7097.77
01:02:02.5	1044314.58	1027744.33	16570.25	7101.51
01:02:03.5	1044325.17	1027746.56	16578.62	7105.10
01:02:04.5	1044335.77	1027748.78	16586.99	7108.69
01:02:05.5	1044346.31	1027751.00	16595.31	7112.25
01:02:06.5	1044356.17	1027753.22	16602.95	7115.52

Table 45 (contd)

Time, GMT	Doppler frequency, Hz	Hypothetical doppler frequency at lunar surface, Hz	Difference, Hz	Velocity referenced to lunar surface, ft/s
01:02:07.5	1044367.32	1027755.44	16611.88	7119.35
01:02:08.5	1044377.75	1027757.66	16620.09	7122.87
01.02:09.5	1044388.92	1027759.88	16629.04	7126.71
01:02:10.5	1044399.36	1027762.09	16637.26	7130.23
01:02:11.5	1044409.64	1027764.31	16645.34	7133.69
01:02:12.5	1044420.66	1027766.52	16654.13	7137.46
01:02:13.5	1044431.72	1027768.74	16662.98	7141.25
01:02:14.5	1044442.91	1027770.95	16671.96	7145.10
01:02:15.5	1044449.52	1027773.16	16676.36	7146.99
01:02:16.5	1044338.22	1027775.37	16562.85	7098.34
01:02:17.5	1044131.90	1027777.58	16354.31	7008.97
01:02:18.5	1043918.71	1027779.79	16138.92	6916.66
01:02:19.5	1043695.41	1027782.00	15913.40	6820.01
01:02:20.5	1043458.73	1027784.21	15674.52	6717.63
01:02:21.5	1043209.46	1027786.42	15423.04	6609.85
01:02:22.5	1042950.62	1027788.62	15162.00	6497.98
01:02:23.5	1042686.36	1027790.83	14895.54	6383.78
01:02:24.5	1042418.04	1027793.03	14625.01	6267.84
01:02:25.5	1042145.38	1027795.23	14350.14	6150.04
01:02:26.5	1041870.14	1027797.44	14072.70	6031.14
01:02:27.5	1041592.87	1027799.64	13793.24	5911.37
01:02:28.5	1041312.03	1027801.84	13510.20	5790.06
01:02:29.5	1041027.50	1027804.04	13223.46	5667.18
01:02:30.5	1040738.57	1027806.23	12932.34	5542.41
01:02:31.5	1040442.12	1027808.43	12633.69	5414.42
01:02:32.5	1040137.35	1027810.63	12326.73	5282.87
01:02:33.5	1039824.78	1027812.82	12011.96	5147.97
01:02:34.5	1039505.19	1027815.02	11690.17	5010.06
01:02:35.5	1039178.23	1027817.21	11361.02	4868.99
01:02:36.5	1038842.26	1027819.40	11022.86	4724.07
01:02:37.5	1038498.34	1027821.59	10676.75	4575.73
01:02:38.5	1038144.24	1027823.79	10320.45	4423.04
01:02:39.5	1037781.10	1027825.98	9955.13	4266.47
01:02:40.5	1037409.65	1027828.16	9581.48	4106.34
01:02:41.5	1037028.91	1027830.35	9198.55	3942.22
01:02:42.5	1036639.61	1027832.54	8807.07	3774.45
01:02:43.5	1036241.77	1027834.73	8407.05	3603.01
01:02:44.5	1035834.70	1027836.91	7997.79	3427.61
01:02:45.5	1035418.82	1027839.09	7579.73	3248.44
01:02:46.5	1034993.39	1027841.28	7152.11	3065.18
01:02:47.5	1034556.97	1027843.46	6713.51	2877.21
01:02:48.5	1034109.58	1027845.64	6263.93	2684.53
01:02:49.5	1033651.02	1027847.82	5803.20	2487.08
01:02:50.5	1033181.01	1027850.00	5331.01	2284.71
01:02:51.5	1032698.53	1027852.18	4846.35	2077.00
01:02:52.5	1032201.88	1027854.36	4347.52	1863.32
01:02:53.5	1031690.91	1027856.54	3834.37	1643.30
01:02:54.5	1031168.35	1027858.71	3309.64	1418.41
01:02:55.5	1030650.71	1027860.89	2789.82	1195.64
01.02:56.5	1030137.70	1027863.06	2274.64	974.84
01:02:57.5	1029654.35	1027865.23	1789.12	766.76
01:02:58.5	1029314.10	1027867.41	1446.70	620.01
01:02:59.5	1029132.71	1027869.58	1263.13	541.34
01:03:00.5	1029030.92	1027871.75	1159.17	496.79
01:03:01.5	1028968.56	1027873.92	1094.64	469.13
01:03:02.5	1028930.73	1027876.09	1054.65	451.99

Table 45 (contd)

Time, GMT	Hz Doppler frequency,	Hypothetical doppler frequency at lunar surface, Hz	Difference, Hz	Velocity referenced to lunar surface, ft/s
01:03:03.5	1028909.59	1027878.25	1031.34	442.00
01:03:04.5	1028898.64	1027880.42	1018.22	436.38
01:03:05.5	1028891.27	1027882.59	1008.68	432.29
01:03:06.5	1028885.90	1027884.75	1001.14	429.06
01:03:07.5	1028882.08	1027886.91	995.17	426.50
01:03:08.5	1028878.43	1027889.08	989.35	424.01
01:03:09.5	1028871.49	1027891.24	980.25	420.10
01:03:10.5	1028862.54	1027893.40	969.13	415.34
01:03:11.5	1028853.87	1027895.56	958.31	410.70
01:03:12.5	1028843.15	1027897.72	945.43	405.18
01:03:13.5	1028833.63	1027899.88	933.75	400.18
01:03:14.5	1028834.12	1027902.04	932.09	399.47
01:03:15.5	1028836.17	1027904.19	931.98	399.42
01:03:16.5	1028837.46	1027906.35	931.12	399.05
01:03:17.5	1028838.15	1027908.50	929.64	398.42
01:03:18.5	1028840.05	1027910.66	929.40	398.31
01:03:19.5	1028841.95	1027912.81	929.14	398.20
01:03:20.5	1028843.71	1027914.96	928.75	398.03
01:03:21.5	1028844.61	1027917.11	927.50	397.50
01:03:22.5	1028845.60	1027919.26	926.34	397.00
01:03:23.5	1028847.84	1027921.41	926.43	397.04
01:03:24.5	1028850.57	1027923.56	927.01	397.29
01:03:25.5	1028851.72	1027925.70	926.02	396.86
01:03:26.5	1028852.91	1027927.85	925.06	396.45
01:03:27.5	1028855.21	1027930.00	925.21	396.52
01:03:28.5	1028856.20	1027932.14	924.05	396.02
01:03:29.5	1028857.87	1027934.28	923.58	395.82
01:03:30.5	1028859.73	1027936.43	923.31	395.70
01:03:31.5	1028861.45	1027938.57	922.88	395.52
01:03:32.5	1028862.85	1027940.71	922.14	395.20
01:03:33.5	1028864.21	1027942.85	921.36	394.87
01:03:34.5	1028865.09	1027944.99	920.10	394.33
01:03:35.5	1028866.83	1027947.13	919.70	394.16
01:03:36.5	1028868.81	1027949.26	919.55	394.09
01:03:37.5	1028870.80	1027951.40	919.41	394.03
01:03:38.5	1028872.01	1027953.53	918.48	393.63
01:03:39.5	1028873.72	1027955.67	918.05	393.45
01:03:40.5	1028876.65	1027957.80	918.85	393.79
01:03:41.5	1028877.89	1027959.93	917.95	393.41
01:03:42.5	1028880.63	1027962.06	918.56	393.67
01:03:43.5	1028882.17	1027964.20	917.97	393.42
01:03:44.5	1028883.05	1027966.32	916.73	392.88
01:03:45.5	1028884.96	1027968.45	916.51	392.79
01:03:46.5	1028886.32	1027970.58	915.74	392.46
01:03:47.5	1028887.52	1027972.71	914.81	392.06
01:03:48.5	1028890.05	1027974.83	915.22	392.23
01:03:49.5	1028891.80	1027976.96	914.84	392.07
01:03:50.5	1028893.90	1027979.08	914.81	392.06
01:03:51.5	1028895.27	1027981.21	914.06	391.74
01:03:52.5	1028896.82	1027983.33	913.50	391.50
01:03:53.5	1028898.62	1027985.45	913.17	391.36
01:03:54.5	1028899.61	1027987.57	912.04	390.87
01:03:55.5	1028900.79	1027989.69	911.10	390.47
01:03:56.5	1028902.24	1027991.81	910.43	390.18
01:03:57.5	1028904.57	1027993.92	910.64	390.27
01:03:58.5	1028905.96	1027996.04	909.92	389.96

Table 45 (contd)

Time, GMT	Doppler frequency, Hz	Hypothetical doppler frequency at lunar surface, Hz	Difference, Hz	Velocity referenced to lunar surface, ft/s
01:03:59.5	1028908.15	1027998.16	910.00	390.00
01:04:00.5	1028909.22	1028000.27	908.95	389.55
01:04:01.5	1028911.81	1028002.38	909.43	389.75
01:04:02.5	1028914.29	1028004.50	909.79	389.91
01:04:03.5	1028914.67	1028006.61	908.06	389.17
01:04:04.5	1028905.48	1028008.72	896.76	384.32
01:04:05.5	1028897.72	1028010.83	886.89	380.09
01:04:06.5	1028889.92	1028012.94	876.98	375.85
01:04:07.5	1028882.34	1028015.05	867.29	371.70
01:04:08.5	1028871.07	1028017.15	853.92	365.96
01.04.09.5	1028866.25	1028019.26	846.99	362.99
01:04:10.5	1028857.07	1028021.37	835.71	358.16
01:04:11.5	1028848.77	1028023.47	825.30	353.70
01:04:12.5	1028841.91	1028025.57	816.33	349.86
01:04:13.5	1028833.66	1028027.68	805.98	345.42
01:04:14.5	1028825.91	1028029.78	796.13	341.20
01:04:15.5	1028818.47	1028031.88	786.59	337.11
01:04:16.5	1028811.79	1028033.98	777.81	333.35
01:04:17.5	1028804.30	1028036.08	768.22	329.24
01:04:18.5	1028797.47	1028038.18	759.30	325.41
01:04:19.5	1028789.02	1028040.27	748.75	320.89
01:04:20.5	1028780.04	1028042.37	737.67	316.14
01:04:21.5	1028766.77	1028044.46	722.31	309.56
01:04:22.5	1028754.91	1028046.56	708.35	303.58
01:04:19.5	1028789.02	1028048.65	693.37	297.16
01:04:24.5	1028728.86	1028050.74	678.11	290.62
01:04:25.5	1028716.46	1028052.84	663.63	284.41
01:04:26.5	1028704.21	1028054.93	649.28	278.26
01:04:27.5	1028691.50	1028057.02	634.49	271.92
01:04:28.5	1028679.08	1028059.10	619.98	265.70
01:04:29.5	1028666.35	1028061.19	605.16	259.35
01:04:30.5	1028653.06	1028063.28	589.78	252.76
01:04:31.5	1028640.89	1028065.37	575.52	246.65
01:04:32.5	1028628.40	1028067.45	561.03	240.44
01:04:33.5	1028615.75	1028069.53	546.22	234.09
01:04:34.5	1028603.37	1028071.62	531.75	227.89
01:04:35.5	1028590.69	1028073.70	516.99	221.57
01:04:36.5	1028578.15	1028075.78	502.37	215.30
01:04:37.5	1028565.02	1028077.86	487.16	208.78
01:04:38.5	1028551.54	1028079.94	471.60	202.11
01:04:39.5	1028539.78	1028082.02	457.76	196.18
01:04:40.5	1028528.44	1028084.10	444.35	190.43
01:04:41.5	1028518.29	1028086.17	432.11	185.19
01:04:42.5	1028510.44	1028088.25	422.20	180.94
01:04:43.5	1028501.79	1028090.32	411.47	176.34
01:04:44.5	1028493.93	1028092.40	401.53	172.08
01:04:45.5	1028486.33	1028094.47	391.86	167.94
01:04:46.5	1028477.42	1028096.54	380.88	163.23
01:04:47.5	1028469.92	1028098.61	371.30	159.13
01:04:48.5	1028461.64	1028100.68	360.96	154.69
01:04:49.5	1028455.77	1028102.75	353.02	151.29
01:04:50.5	1028448.55	1028104.82	343.73	147.31
01:04:51.5	1028443.09	1028106.89	336.20	144.09
01:04:52.5	1028436.11	1028108.96	327.16	140.21
01:04:53.5	1028430.27	1028111.02	319.25	136.82
01:04:54.5	1028423.61	1028113.09	310.52	133.08

Table 45 (contd)

Time, GMT	Doppler frequency, Hz	Hypothetical doppler frequency at lunar surface, Hz	Difference, Hz	Velocity referenced to lunar surface, ft/s
01:04:55.5	1028418.39	1028115.15	303.24	129.96
01:04:56.5	1028413.42	1028117.21	296.21	126.95
01:04:57.5	1028407.24	1028119.27	287.96	123.41
01:04:58.5	1028402.59	1028121.33	281.25	120.54
01:04:59.5	1028398.08	1028123.39	274.69	117.72
01:05:00.5	1028392.38	1028125.45	266.93	114.40
01:05:01.5	1028386.85	1028127.51	259.33	111.14
01:05:02.5	1028381.60	1028129.57	252.03	108.01
01:05:03.5	1028377.99	1028131.62	246.37	105.58
01:05:04.5	1028374.55	1028133.68	240.87	103.23
01:05:05.5	1028368.74	1028135.73	233.01	99.86
01:05:06.5	1028365.88	1028137.79	228.09	97.75
01:05:07.5	1028361.33	1028139.84	221.49	94.92
01:05:08.5	1028358.67	1028141.89	216.78	92.91
01:05:09.5	1028355.42	1028143.94	211.48	90.63
01:05:10.5	1028350.42	1028145.99	204.43	87.61
01:05:11.5	1028348.07	1028148.04	200.03	85.73
01:05:12.5	1028344.89	1028150.09	194.81	83.49
01:05:13.5	1028342.58	1028152.14	190.44	81.62
01:05:14.5	1028339.65	1028154.18	185.47	79.49
01:05:15.5	1028329.56	1028156.23	173.33	74.28
01:05:16.5	1028318.50	1028158.27	160.23	68.67
01:05:17.5	1028308.24	1028160.31	147.92	63.40
01:05:18.5	1028299.91	1028162.36	137.55	58.95
01:05:19.5	1028291.46	1028164.40	127.09	54.46
01:05:20.5	1028284.13	1028166.44	117.69	50.44
01:05:21.5	1028277.81	1028168.48	109.33	46.86
01:05:22.5	1028268.83	1028170.52	98.31	42.13
01:05:23.5	1028257.23	1028172.55	84.67	36.29
01:05:24.5	1028245.70	1028174.59	71.11	30.48
01:05:25.5	1028233.02	1028176.63	56.39	24.17
01:05:26.5	1028222.26	1028178.66	43.60	18.68
01:05:27.5	1028212.00	1028180.70	31.30	13.42
01:05:28.5	1028208.49	1028182.73	25.76	11.04
01:05:29.5	1028205.73	1028184.76	20.97	8.99
01:05:30.5	1028202.47	1028186.79	15.68	6.72
01:05:31.5	1028200.32	1028188.82	11.50	4.93
01:05:32.5	1028201.51	1028190.85	10.66	4.57
01:05:33.5	1028204.19	1028192.88	11.91	4.85
01:05:34.5	1028206.24	1028194.91	11.33	4.86
01:05:35.5	1028207.62	1028196.93	10.69	4.58
01:05:36.5	1028211.14	1028198.96	12.18	5.22
01:05:37.5	1028214.81	1028200.98	13.83	5.93
01:05:38.5	1028202.80	1028203.01	0.20	0.09
01:05:39.5	1028208.13	1028205.03	3.10	1.33
01:05:40.5	1028209.23	1028207.05	2.17	0.99
01:05:41.5	1028211.08	1028209.07	2.01	0.86
01:05:42.5	1028212.93	1028211.09	1.83	0.79
01:05:43.5	1028214.24	1028213.11	1.12	0.48
01:05:44.5	1028216.55	1028215.13	1.42	0.61
01:05:45.5	1028217.96	1028217.15	0.81	0.35
01:05:46.5	1028220.14	1028219.16	0.98	0.42
01:05:47.5	1028221.48	1028221.18	0.30	0.13
01:05:48.5	1028223.20	1028223.19	0.00	0.00
01:05:49.5	1028225.11	1028225.21	−0.09	−0.04
01:05:50.5	1028226.74	1028227.22	−0.48	−0.21

Glossary

AFETR	Air Force Eastern Test Range
AFC	automatic frequency control
AGC	automatic gain control
AMR	altitude marking radar
APC	automatic phase control
AOS	acquisition of signal
ASEC	alpha scattering electronics compartment
ASI	alpha scattering instrument
ASSH	alpha scattering sensor head
A/SPP	antenna and solar panel positioner
BECO	booster engine cutoff
CDC	command data console
CKAFS	Cape Kennedy Air Force Station
DPES	direct-ascent powered flight simulator
DSIF	Deep Space Instrumentation Facility
DSN	Deep Space Network
DSS	Deep Space Station
FPAC	flight-path analysis and command
FM	frequency modulation
GCF	ground communications facility
GSFC	Goddard Space Flight Center
HAC	Hughes Aircraft Co.
HPPS	Hughes post processor
ICS	intracommunications system
I/O	input/output
KSC	Kennedy Space Center
LOS	loss of signal
MECO	main engine cutoff
MEIG	main engine ignition
MES	main engine stuart (*Centaur*)
MSFN	Manned Space Flight Network
MTGS	midcourse and terminal guidance
NASCOM	NASA Communications System
ODGX	orbit data generator program
ODPX	orbit determination program
ORT	operational readiness test
OSAS	on-site alpha scattering (program)
PCM	pulse code modulation
PLIM	postlaunch instrumentation message
PM	phase modulation
PRDX	JPL predicts program
RADVS	radar altimeter and doppler velocity sensor
RIS	range instrumentation ship
RTCS	real-time computer system
SCAMA	signaling, conferencing, and monitoring arrangement
SCO	subcarrier oscillator
SECO	sustainer engine cutoff
SFOF	Space Flight Operations Facility
SM/SS	soil mechanics/surface sampler
SOCP	*Surveyor* on-site computer program
SPAC	spacecraft performance analysis and command (group)
SRT	system readiness test
TDA	tracking and data acquisition
TDH	tracking data handling
TDM	time division multiplex
TDPX	tracking data processor program
TDS	Tracking and Data System
TRJX	JPL trajectory program
TTY	teletype
VCO	voltage-controlled oscillator
VCXO	voltage-controlled crystal oscillator
VECO	vernier engine cutoff
WBVCXO	wideband voltage-controlled crystal oscillator